PROFESSIONAL PAPERS

INDIAN ENGINEERING.

[SECOND SERIES.]

EDITED BY

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PRINCIPAL, THOMASON C. E. COLLEGE, ROORKEE.

VOL. I.

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PREFACE TO VOL. I.

THE first volume of the New Series is now concluded, and will be acknowledged, I hope, to be equal in interest to any of its predecessors in the First Series. For this I have to thank the many able contributors who have furnished original articles, and the Government of India in the P. W. Department, who have supplied Resolutions and Reports of general interest to the Engineering profession in this country.

Considering, however, the large number of Officers serving the Government of India in the P. W. Department, (more than 1000 in the Engineer Establishment,) in addition to very many Engineers employed upon Railways, &c., under private Companies, it must be admitted that the staff of Contributors to this periodical bears but a very small proportion to the total number of Engineers who might be reasonably expected to support it as an organ for disseminating information and ventilating opinions on "Indian Engineering." This may be attributed principally to the fact that all Engineers in this country are very heavily burdened with work, and the greater their ability and experience the more extensive and engrossing are their duties, so that very few have leisure to devote to writing "Articles," or Reports beyond such as are required from them by Government. Many, moreover, who might find time to supply short articles are averse from writing on topics and details which from their familiarity appear to be trite and common place. Such details, however, are often those which would prove of most interest and value to their brother Engineers, who having to undertake some particular work, may at the

outset lack the familiarity which has been gradually and insensibly acquired by other Members of the Profession who have been for some time perhaps engaged on work of an exactly similar nature.

I would request those Contributors and Subscribers who have hitherto supported this Periodical, to exert their influence to extend its circulation, so that a greater variety of subjects may be represented in its pages, and that some reduction may be made in its price, which is necessarily at present high, owing to the comparatively small list of Subscribers.

Of the 62 papers forming this volume, 13 refer to Irrigation, Water Supply or Drainage: 5 are descriptive of Public Buildings: 5 relate to Cements and Mortars; 5 to Surveying and Mathematical Instruments: while Road-Making, Bridge Building, Brick Manufacture, Timber, Iron, Masonry, Well Sinking, Strength of Materials and Structures, Light-houses, Rail and Tramways, and other subjects are discussed in one or more articles.

The absence of articles on Railways in India is to be regretted, and will, it is hoped, be rectified in future numbers : the progress of the State Railways on the New Metre gauge will furnish for description and discussion matter of a most interesting nature, and involving much of novelty.

It is proposed that the Second Volume shall consist of Four Quarterly Numbers, issued in January, April, July and October, 1873 : the cost remaining 14 Rs. for Subscribers in advance ; but 4 Rs. a number for those paying in arrears, and for purchasers of single numbers.

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ERRATA.

Vol. I. [Second Series.]

Page 28, in note—inseıt the word *not* between "are" and "measured."

,, 29, first lıne *for*

$$“q'x = \frac{x}{2} - \frac{t}{2} \therefore q = \frac{Ph}{3V} - \frac{x-t}{2}” \textit{ read}$$

$$“q'x = \frac{x-t}{2} \cdot \frac{x+2t}{3(x+t)} \therefore q = \frac{Ph}{3Vx} - \frac{x-t}{2} \cdot \frac{x+2t}{3x(x+t)}”$$

, 148, line 2 and 3 *for* "ın its" *read* "it has a."

,, 154, line 6 from bottom *for* "d'" *read* "p'."

,, 158, line 3 *for*

$$“\therefore CG' = \left(\frac{x}{2} + \frac{rh}{3} + \frac{t}{6} - \frac{x}{6}\right) \cdot \frac{x+2t}{x+t} = \left(\frac{x+rh}{3} + \frac{t}{6}\right)\frac{x+2t}{x+t}.”$$

read

$$“\therefore CG' = \frac{x}{2} + \left(\frac{rh}{3} + \frac{t-x}{6}\right)\frac{x+2t}{x+t}.”$$

,, 158, line 7 *for* "(a)" *read* "(f)."

,, ,, line 10 *for*

$$“\therefore CG' = \left(\frac{x}{2} + \frac{x}{6} - \frac{r'h}{3} - \frac{t}{6}\right)\frac{x+2t}{x+t} = \left(\frac{2x-r'h}{3} - \frac{t}{6}\right)\frac{x+2t}{x+t}.”$$

read

$$“\therefore CG' = \frac{x}{2} + \left(\frac{x-t}{6} - \frac{r'h}{3}\right)\frac{x+2t}{x+t}.”$$

In article No. XV. (No. 2.) throughout article, *for* "Dr. Brewster," *read* "Dr. Brewer."

CONTENTS.

No. XXIII.

METAL CONSOLIDATION BY STEAM ROLLERS IN THE CENTRAL PROVINCES.

BY G. W. MACGEORGE, *Exec. Engineer, Kanhán Division.*

Kamptí. 26 January, 1871.

FOR greater clearness, I propose treating the subject in the following order:—

1st.—General sketch of the order of the season's working.

2nd.—Expenditure.

3rd.—Fuel used.

4th.—General conclusion.

5th.—Appendix.

It will be unnecessary for me to enter into any description of the mechanical details of the steam road roller, as these are already known to you, and are moreover sufficiently entered into by Mr. Davidson in his report, which I have appended.

As you are aware, two of Messrs. Aveling and Porter's steam road rollers arrived at the end of the rainy season of last year, and were put together by Mr. O'Callaghan. One of the rollers was tried on a short length of new metal, but so late was it in the season that no very definite information was obtained as to the capabilities of the machine, or of the accessory appliances requisite in this country to ensure its most expeditious and convenient action.*

* *Vide* P. P., Old Series, Vol. VII., pp. 145-151.—ED.

The operations conducted this year may therefore be fairly considered as tentative and experimental. None of the existing staff of the Division had any previous practical knowledge of the working of the roller, and the very small amount of printed information as to the working results of the machine in England could not prove of much value, owing to the totally different set of conditions to which they referred.

In Europe the value of steam road rolling has been very generally acknowledged, as compared with the systems previously adopted in consolidating metal, these systems being either consolidation solely by the traffic or horse rolling.

In India we have to compare it with what is undoubtedly a very perfect, if expensive, system of consolidation, viz., hand ramming. The operations had moreover in the case under report to be conducted over a considrable extent of road entirely in the jungles, whilst in England the use of the steam roller has (so far as I am aware) been hitherto confined to short lengths at a time in the immediate neighbourhood of towns, with all the attendant conveniences of unlimited water supply and facilities for skilled labor in a humid and highly favorable climate. These distinctions are necessary to point out, as they show that the roller had to be adapted in a great measure to a novel set of conditions, and that therefore the highest results cannot reasonably be expected until experience has suggested the most favorable manner of meeting or avoiding the many petty difficulties of detail, on every one of which increased rapidity of work and consequent further economy may depend.

The first roller put together and taken up the road last year by Mr. O'Callaghan was shortly afterwards despatched to Jabalpur for work there. The second roller (the cast-iron turn-table frame and spur wheel of which had been accidentally broken) was not without some difficulty repaired in the Kanhán Workshops, a sun awning was fitted, and a large four-wheeled tender, or fuel waggon, on Messrs. Aveling and Porter's pattern was made up. Towards the commencement of the rains the machine was steamed up to Amrie, and fuel was stored in the out-buildings at this place, and also at Chorbowlie and Korai, consisting of Chanda, Chhindwara, and English coals. The coals being used chiefly in order to test the comparative economic values of the Native coals, and to show also the relative economy of the employment of wood in the furnaces as at present constituted.

The illness of the European driver of the roller, and a difficulty in collecting gangs of work-people in sufficient numbers for spreading and watering the metal with the requisite rapidity at one spot, caused some delays at starting, so that the roller was not fairly at work on the 57th mile until the 19th July. The miles for which new metal had been collected were as follows —The 21st to the 31st, both inclusive, the 41st and 42nd, the 45th, the 49th and 57th, in all 16 miles. The first eleven miles stretching from near the village of Doomrie to Chorbowlie, two miles close to Deolapar, the remaining three being between this place and the foot of the Korai ghât

The 57th mile at Korai was the one first commenced on, about a quarter of a mile had been previously picked up and spread by hand. The roller was passed over this length in every part four times, during unusually heavy rain, when the metal was found to be well consolidated.

The remainder of the mile was then picked up by the machine by inserting the spikes in the holes provided in the forward rollers, and the result proved satisfactory, the whole surface of the road being so loosened as to permit its being rapidly raked into a disjointed mass of stones with the point of a pick. This operation, together with the subsequent spreading and rolling of the metal at this place, was conducted during heavy rain. After the roller had passed four times over each part, the road assumed a hard compact appearance, the whole mile was then twice gone over, thus making in all six rollings, when it was found to be thoroughly consolidated and finished. Scarcely any labor has since been expended in keeping this mile in order, which, as it affords the best results of the whole season's working, will be alluded to in detail further on.

The engine was removed to the 49th mile on the 27th July. From the 28th of this month to the 6th September no rain fell at any of the places where the roller was at work, comprising the 49th, 45th, 42nd, 41st, 30th, 29th, 28th and 27th miles. During this period a rain-fall amounting to 4 inches in all was registered at Kamthi. After the first week water was difficult to procure, that in the side drains having completely dried up. During the month of September the roller was employed on the 26th, 25th, 24th, 23rd, and 22nd miles, and scarcely any rain fell, the amount registered at Kamthi being less than 5 inches. From the end of September to the 15th October the roller completed the 21st mile, and was engaged in reconsolidating all the miles between Doomrie and

Chorbowlie, under similar conditions of weather, hardly 1 inch being registered at Kamthi during these 15 days; in all, barely $9\frac{1}{2}$ inches of rainfall was registered in Kamthi from the 28th July to the 15th October. This great want of water during the greater duration of the operations very injuriously effected the economical results of the working, and obliged me reluctantly to go over a considerable portion of the new rolled metal once with hand rammers. In spite, however, of this additional expense, and the extra number of times the roller had to be taken over the metal, and the various other difficulties and delays due to the want of sufficient water, the actual cost of the consolidation has not exceeded two-thirds of the usual rate for this work when executed by hand labor, and it has more than come up to the saving of Rs. 100 per mile estimated by Mr. O'Callaghan in his report of last year; whilst, as will be shown, if the mean between the actual saving on the 57th mile, done under the most favorable conditions, and that on the other miles be taken, the result is much beyond this estimate.

Before entering into any detailed account of the expenditure incurred this season in consolidating the 16 miles of new metal laid down by means of the steam road roller, I will first exhibit the actual expenditure incurred in previous years on consolidation on the Northern Road by the usual hand labor method, so as to institute a direct comparison of actual mileage rates. This general comparison will include the expense in both cases of nokur coolies for keeping the new metal in order for two months, and of such operations as picking up and spreading metal common to both systems, and it will be based on the supposition that the work is perfectly done in each case; contingent advantages in the use of the steam roller over and above the actual consolidation of the new metal, such as the improvement to the whole intermediate lengths of road over which it must pass to reach its points of working, will not be considered. My first object being merely a broad and general contrast of the actual cost of the two systems from actual finished operations, the hand labor being based on several seasons work; the machine labor, from this season's work only.

The following are derived from the completion reports of the consolidation of metal on the Northern Road in the three previous years. The metalled width being then, as now, 12 feet, and the usual thickness of the coats of metal 4 inches.

TABLE A.

Former years.	Executed quantity cubic feet.	Cost.	Finished rate per 100 cubic feet.	Finished rate per mile.
		RS. A. P	RS. A P.	RS. A. P.
1867-68, .. 29½ miles, ..	625,665	9,896 1 2	1 9 8	335 8 0
1868-69*, 93, " ..	1,953,600	45,896 12 2	2 5 7	493 8 0
1869-70, .. 24⅓, " ..	515,459	8,481 6 6	1 10 4	349 2 0
1870-71, .. 16 miles, .. By steam road roller— Miles. 11 3 inches coat. 174,240; 5 4 do 105,600; 279,840	279,840	3,180 7 4	1 2 2	198 12 5

In the year 1868-69* a very long length appears to have been consolidated, and a number of the miles near and beyond Seoni were laid with basalt metal, the rate for which is always higher than for granite or limestone; I therefore exclude this year from the comparison. Taking then the two seasons 1867-68 and 1869-70, we have a mean rate per mile of $\frac{335\text{-}8\text{-}0 + 349\text{-}2\text{-}0}{2}$ equal Rs. 342-5-0, as compared with this year's rate of Rs. 198-12-5, showing a saving (even under the disadvantageous circumstances under which the work was conducted) of Rs. 342-5-0 – Rs. 198-12-0 = Rs. 143-9-0 per mile.

I will now proceed to give an abstract of the charges incurred in consolidating the 16 miles of metal, which make up the total expenditure of Rs. 3,180-7-4, these are as follows :—

ABSTRACT OF CHARGES.

TABLE B.

Head of Abstract.	Items of charge.		Total Amount.	Amount per 100 cubic feet of metal.	Amount per mile.
		RS A P.	RS. A. P.	RS. A. P.	RS. A. P.
ESTABLISHMENT.	Steersman's pay, ..	111 1 9			
	Stokers, do., ...	49 1 4			
	Chowkeedars and coolies watering boiler,	36 5 3	196 8 4	0 1 1·4	12 4 6¼

Head of Abstract	Items of charge.		Total Amount	Amount per 100 cubic feet of metal.	Amount per mile.
		RS. A. P.	RS. A. P.	RS. A. P.	RS. A. P.
FUEL.	English coal, 4½ mds.,	98 9 0			
	Chhindwara coal, 282½ maunds,	388 7 0			
	Chanda coal, 59½ mds.,	81 13 0			
	Firewood, including cutting and transport 317½ mds., ..	119 11 3			
	Carriage hire, ...	22 0 0	710 8 3	0 4 2·7	46 4 $6\frac{3}{16}$
COOLIE LABOR. In spreading metal and moorum, occasional picking up, watering, extra ramming, &c.	Spreading metal, ..	525 0 0			
	Spreading moorum, .	130 0 0			
	Occasional picking up,	16 0 0			
	Watering, extra ramming over by hand labor, ...	961 4 1	1,632 4 1	0 9 3·9	102 0 $3\frac{1}{16}$
INCIDENTAL CHARGES. Due to roller, divided into labor in cleaning, and allowance, and sundry repairs and issue of stock, (such as ropes, baskets, water-pots, oil, cotton waste), &c.	Labor in cleaning and allowance and sundry repairs, ..	88 1 5			
	Issue of stock, ...	42 1 3	130 2 8	0 0 8·9	8 2 2
NOKER COOLIES.	For two months, ..	481 0 0	481 0 0	0 2 8·9	30 1 0
	Total, ..	3,180 7 4	3,180 7 0	1 2 2	198 12 5½

I may here remark that the European driver is not included in the above establishment charges, it could not fairly be charged unless the pay of Overseers are included in the rates for hand labor. In carrying out consolidation of metal extending over 50 miles of road by hand labor, all the work would probably go on simultaneously. Two Overseers at least would therefore be necessary, whereas in consolidation by the steam roller the work is always at one spot, one Overseer in addition to the driver (who ranks as a Supervisor) is alone requisite.

The driver's pay may therefore stand for the pay of the second Overseer required under the other system.

Under the head of abstract "Fuel" it is necessary to remember that the quantity consumed is the whole quantity chargeable to the work and not that consumed purely in picking up or rolling metal. The roller was steamed from Kamthi to Korai and back, this distance being 58 by 2 miles, equal 116 miles; out of this 16 miles of new metal was rolled, so that striking out the fuel used in actual operations, a further amount necessary to carry the roller once over 100 miles of road was consumed, thus the amount per mile shown on the table does not represent the cost of fuel actually expended in finishing the rolling of one mile of metal, but the gross cost per mile of road consolidated. The actual consumption and cost of fuel used in rolling once or any given number of times a mile of new metal, can only be arrived at by the actual observation made during the progress of the work. These observations will be found in Table I of Mr. Davidson's Report.

My Table B. shows the total expenditure due to each item of work extending over the whole 16 miles of metal consolidated, including the cost of transporting the roller the additional 100 miles, from which the average expenditure per 100 cubic feet and per mile for each head of abstract is determined; the expenditure per actual mile will of course vary considerably according to the various conditions of weather, of gradients, of nearness of metal stack, facilities for watering, and a multitude of other circumstances; nothing would be gained beyond complexity and confusion in illustrating the detail of expenditure on each actual mile; as, however, the work on the 57th mile at Korai was, as previously remarked, conducted under very favourable conditions of weather, being finished after six rollings and has required almost no work whatever to keep it in order after the roller left it, I think this mile may be taken as a test of the results to be expected under the best conditions; a mean between this and the average mileage expenditure on the remaining 15 miles conducted under exceptionally bad conditions as to weather, will, I think, give a fair approximation to the real mileage rates, had the season been favourable, although I am of opinion that further improvements in the order of working indicated by the experience gained and the entire use of wood-fuel will, when carried out, very materially reduce these rates in future operations.

The 57th mile was laid with granite metal, 4 inches thick and 12 feet wide.

Table C.

Showing actual expenditure on the 57th mile at Korai by Steam Road Roller, and comparison with hand labor.

Steam Roller.								Hand Labor.			
Head of Abstract.	Items of charge				Total Amount			Items of charge	Total Amount		
		Rs.	A	P	Rs.	A	P.	Rs. A. P.	Rs	A.	P.
Establishment	Steersman's pay	20	15	10							
	Stokers do and sundry coolies	7	0	11	28	0	9				
Fuel. Cutting and cutting up wood, picking up ¼ of the mile by machine, and rolling the whole six times.	Cutting and cutting up wood	24	14	3							
	Wood, 70 maunds at 0-6-0 per md.	26	4	0	51	2	3				
Coolie labor. Spreading metal and moorum and picking up ¼ of a mile.	Spreading metal	39	8	0							
	Do moorum	8	0	0							
	Picking up ¼ mile by hand picks	4	0	0	51	8	0	Picking up 1 mile, ..	16	0	0
								Spreading metal 1 mile,	39	8	0
								Do. moorum 1 mile, ..	8	0	0
								Ramming and watering 1 mile, ..	248	13	0
Incidental Charges— Baskets, ropes, oil, cotton waste, cleaning engine, &c.	Incidental charges	13	9	0	13	9	0				
Noker Coolies. Keeping in repair.	Keeping in repair	7	4	0	7	4	0	Keeping in in repair for 2 months, ..	30	0	0
	Total, ..				151	8	0	Total, ..	342	5	0
					=0	9	8 per 100 c. feet.		=1	9	11 per 100 c feet.

The saving on this mile taken singly, or Rs. 342-0-5 – 151·8 equals Rs. 190-13-0 on the average mileage rates of two past seasons; that the total saving per mile on the whole length only reaches Rs. 143-9-0 is due principally to extra expenditure due to watering during exceptionally dry weather, going over the metal an excessive number of times with the roller where water was not met with, and the cost of having to go over much of the metal once with gangs of hand rammers. If from the total expenditure of Rs. 3,180-7-4 (*see* Table B.), we now deduct Rs. 151-8-0, the expenditure on the 57th mile, and divide the remainder by 15 (the remaining number of miles), we have for the average mileage rate of these 15 miles, Rs 201-15-0. Taking a mean between this and the expenditure on the 57th mile, we have $\frac{201\text{-}15\text{-}0 + 151\text{-}8\text{-}0}{2}$ = Rs. 176-11-6, and Rs. 342-5-0 – Rs. 176-11-6 gives us a saving of Rs. 165-9-6 per mile.

The cost of the roller may be taken at	Rs.	8,000
To this add interest at 5 per cent. for two years ..	„	800
And allow for repairs Rs. 400 per year for 2 years, a very ample allowance, ...	„	800
	Total Rs.	9,600

We find that, saving Rs. 160 per mile, the steam roller will pay off all charges after rolling 60 miles of metal in two years, supposing her to roll 30 miles in one rainy season, an amount she could undoubtedly do. Mr. O'Callaghan estimated the work of the roller at a mile a day, this might no doubt be done under the highest favorable circumstances, and with all the minor operations in perfect accord; but the roller also picks up the old road in addition to rolling the metal, this operation cannot be done in less than half a day, so that I am of opinion that it is not safe, taking all the contingencies of working into account, to expect more than an average of one mile in two days.

This season the roller was actually at work on the metal either picking or rolling, and including going and coming from her work, for 64 days, which for 16 miles gives us but one mile in four days; but this cannot be taken as a fair test in this respect, owing to the extra number of times she was taken over the metal dry and the variety of delays caused by what may be called experimental trials of the machine in a number of different ways. Both as regards the general order of the working and the manner of laying and watering the metal and moorum, much experi-

ence has been gained, and on roads where, as at present on the Northern Road, there is no objection in laying down half a mile or a mile of new metal in advance of the roller, I should consider a mile finished in two days as a fair and reasonable amount of work to expect; but I should hesitate in assigning more than this.

As before stated, the fuel used during the progress of the work consisted of proportions of English, Chhindwara, and Chanda coals, and firewood. The total quantities of each kind consumed are shown in my Table B. Actual and careful observations taken by Mr. Davidson and recorded in his Table I. show the relative economic values of each of these fuels, at their present relative costs. In terms of work done Mr Davidson's Table shows that their relative values are as follows:—

	Maunds.	
English coal, ...	1	One mile once rolled
Chanda coal, ...	2	
Chhindwara coal, ...	4	
Wood, ...	4	

That is, one maund of English coal will do the same work as two maunds of Chanda and four of Chhindwara coal, and four maunds of wood.

Their relative economic values will therefore stand as follows:—

	Maunds		Mean rates at site of engine including carriage and cutting in the case of wood				Economic values			
			RS.	A.	P.		RS.	A.	P.	
English coal, ...	1	at	2	8	9	=	2	8	9	One mile once rolled
Chanda coal, ...	2	at	1	6	3	=	2	12	6	
Chhindwara coal, ...	4	at	1	6	5	=	5	9	8	
Wood, ...	4	at	0	7	6	=	1	14	0	

From this it will be seen how much the actual cost of the season's working has been increased by the use of the coals employed. A reference to my Table B. will show a consumption of 282½ maunds of Chhindwara coal. This coal, I need hardly remind you, was that received in transfer from the Nagpur Division; though it had suffered by long exposure, and was in every way inferior as a fuel, it was undoubtedly economical to use it at the stock rate of Rs. 1-6-5 per maund rather than to allow it to deteriorate further and become useless; but at the same time I must not omit to point out how its employment at the stock rate of Rs. 1-6-5 per maund, and its low relative value as a fuel, has affected the working rates

of consolidation, and consequently the saving per mile that might have been shown had wood been employed in the place of it. The small quantities of English and Chanda coals used, act also in the same way, they were used altogether experimentally, not to show the greater economy of wood (as the prices of fuel at present stand), of which there had been no doubt, but as an independent experiment for the purpose of contrasting the value of good English coal and that from the new Chanda coal fields.

It will be worth while however, if, in the place of the coal consumed by the steam road roller, we substitute the equivalent quantities and cost of the wood that might have been employed, so as to show what might have been the mileage saving (other things remaining the same) had wood been used, and consequently what may be done in another year's operations.

	Total used.		Equivalent quantities of wood.
	Maunds.		Maunds.
English coal, ...	41·5 × 4	=	166·0
Chanda coal, ...	59 5 × 2	=	119·0
Chhindwara coal, ...	282 5 × 1	=	282 5
Wood, ...	317·5 × 1	=	317 5
	Total maunds, ..		885 0
	at 7 annas 6 pie = Rs. 414-13-6		

As, however, if wood had been used throughout, some further expenditure would have taken place in cutting up the extra quantity and for carting, owing to its greater bulk as compared with coal, we may allow another anna per maund, which will be outside the mark; we shall have therefore 885 maunds at 8 annas and 6 pie per maund, equal Rs. 470-2-6. Now the total actual expenditure for fuel (see Table B.) is Rs. 740-8-3; the saving, therefore, that would have been effected if wood fuel had been entirely used, other things remaining the same, will equal Rs. 770-8-3 — Rs. 470-2-6 = Rs. 270-5-9 and $\frac{\text{Rs. 270-5-9}}{\text{16 No. of miles}}$ = Rs. 16·9 (say Rs. 17) so that the mileage rate (see Table A.), instead of being Rs. 198-12-0, would have been Rs. 182-12-0 only, or a total saving on the average mileage rate for two past seasons of Rs. 159-9-0, instead of Rs. 143-9-0, the actual saving per mile on the whole work. Again, if the wood had been purchased direct on the road, instead of being charged at

the stock rate, 5 annas per maund, including cartage, would have been ample. We should therefore have had 885 maunds at 5 annas, equal Rs. 276-8-0. This would have given us under head "Fuel" a saving of Rs. 464, equal to Rs. 29 per mile more than the actual saving, that is to say, a total of Rs. 172-9-0 per mile less than old mileage rates by hand labor. From these figures it will be seen how much the actual rates per 100 cubic feet or per mile have been increased by the circumstance of using coal at its present value, and wood at stock rates instead of by direct purchase.

That the savings on the 57th mile (as shown above) reached Rs. 190-15-0 is due to the circumstance that being consolidated for the most part under very heavy rain, little expenditure for watering and extra ramming after the roller left it took place; and, moreover, the number of times the roller was taken over the metal reached a minimum. A glance at Table C. will show that this saving might have reached over Rs. 200 per mile.

The amount under head of Abstract "Establishment" is very large, viz., Rs. 28-0-9, or 9½ days' pay of steersman and stoker, and attendant coolies, instead of two days' pay, equal to about Rs. 6-0-0, in which time the mile might have been finished; that it was not so, was due to the mile being the first one commenced. Each of the separate operations of picking up and spreading metal and rolling with the machine did not at first fit into one another so as to cause a minimum of delay, and any such delay or waiting of the roller will necessarily augment the sub-head of Establishment.

Before closing this part of my report I cannot avoid quoting the following paragraphs from a "Report on the economy of road maintenance through Steam Road Rolling, by Frederick A. Paget, Esq., C.E." At page 29, Mr. Paget states, that according to particulars furnished by Mr. Philip H. Wall, the Engineering Agent in England of the Calcutta Municipality, of trials made in India with the steam road roller by the Engineer to Calcutta Municipality, "The rolling of 44,631 square yards cost £146 4*s.* 6*d.*;" reducing this, I find it to equal about Rs. 230 per mile, of 12 feet roadway. Our actual expenditure has been Rs. 198-12-0 per mile, including keeping in repair for two months; but would nearly equal the above figure if the driver's pay for three months,—equal to about Rs. 500, or Rs. 31 per mile,—be added, this being probably included in the above quotation.

Mr. Davidson in his report having given the results of his observations on the economical values of the fuels used, and the manner of treating the Native coal, it will not be necessary for me to enter further into the matter under this head

Under this heading, I propose treating each detail of the work separately, so that the results of the experience gained on each operation may be condensed in order.

The operation of picking up is carried out by inserting spikes projecting 4 inches from the circumference of the forward rollers into holes provided for the purpose; the spikes are secured by nuts with washers on the inner side The old road is very effectually picked up by this arrangement, the whole surface being completely loosened. A few men with the points of their picks can afterwards easily rake the whole surface into a mass of disjointed stones The work is somewhat trying to the engine, requiring extra care both in driving and steering. It was found (as in fact was expected) that this operation is best carried out during dry weather, and it should not be done on rainy days if it can be avoided.

The engine can pick up a mile in about half a day, including time for fitting in spikes and taking them out again, at an average cost (using wood fuel at 6 annas per maund, of which she would burn about 15 maunds) as follows:—

	RS.	A.	P.
Establishment and stores, half a day,	2	8	0
Fuel, 15 maunds, at 6 annas =	5	10	0
Pickmen to rake together loosened road,	4	0	0
Total ..	12	2	0

Ordinary hand picking costs about Rs. 16 per mile on an average; a saving of about Rs 4 per mile is therefore effected by this operation, or with wood at 5 annas per maund, Rs 5.

Independently of the money saving, the work is undoubtedly done in a much more thorough and effectual manner, and it would probably pay to do it even if it cost more than the hand picking.

In order that continuous work over a considerable length of road may be carried on with a minimum of delay to the roller and the maximum of economy, it is evident that the number of coolies employed in spreading the metal and binding material must bear an exact proportion to the work of the roller in picking up and rolling, as regards time taken in doing equal lengths. The roller should uninterruptedly be able to work either

at one operation or the other for the full number of hours in the day, and the coolies should also be able to work without interruption the same number of hours. That this may be done it is evident that the roller should pick up a greater length of road in the course of the day than she rolls, in order that the gang may have a picked up portion on which to spread metal during the last hours of the day, whilst the roller is consolidating the portion immediately behind, and also that they may be able to begin spreading on the following morning at the same hour the roller commences picking up in front. The utmost economy depends upon a due *apportionment of the number of spreaders to the work of the engine*, so that the latter may never have to wait for the metal being laid down, or the former to wait for the old road to be picked up.

The time necessary for fitting in and taking out the picking up spikes is of course curtailed if the engine divides the day proportionately between the two operations, completing the necessary length of picking up in the first part of the day and then rolling until evening. The following Table will, I think, show an apportionment of a day's work approximately correct:—

Order of operations of engine	No. of hours	Order of operations of Coolies
Getting up steam, fitting spikes, and picking up one mile of old road,	5½	Coolies lay down nearly half mile.
Taking out spikes and rolling and finishing a half mile, ...	3	Coolies lay down over quarter mile, making in all three-quarters of a mile.
Further rolling and finishing a quarter mile.	1½	Gang will work on the remaining quarter mile picked, probably doing about half and leaving the rest to be recommenced on the following morning.
Total, ...	10	

From this Table it will be seen that the effective day's work will consist of one mile picked up, about ⅞ths of a mile spread, and ¾ of a mile rolled and finished. It must be borne in mind, however, that in a long length of road, although ¾ths of a mile finished per day may and will be

frequently done, yet many causes of stoppage of the regular order and continuity of the work must frequently occur. Such, for instance, as (1), occasional repairs or adjustments of the engine; (2), feast days and holidays when the full gangs cannot be collected, (3), very wet days, when they refuse to work; (4), very soft or very hilly portions of road. (5), if a European Driver is employed, the difficulty of his always working the full ten hours per day, owing to the time he expends in having to go perhaps three to five or six miles to the nearest Road Bungalow for his meals. These minor causes of delay will, when added together, in a whole season's working materially affect the average length of road finished per day, and therefore, as before stated, I do not think that in practice over a long length of road it would be prudent to base calculations on more than from $\frac{1}{3}$ to $\frac{1}{2}$ mile completely finished per day. Allowing 90 days in a monsoon working season, this gives 45 miles per year as the maximum of work to expect from one roller.

Turning now to the Table, we find that the coolies must spread nearly half a mile of metal, say 2,600, feet in $5\frac{1}{2}$ hours; allowing that one man and two women will do 40 feet in a day of 10 hours, we shall require a gang of 117 men and 234 women, independent of those required for spreading the moorum and for watering.

The experience gained in the actual working this season appears to show that it is better to put down the moorum in several instalments, after heavy watering much of the moorum is washed into the metal and towards the sides of the road, forming a liquid mass; at first this should be swept back as much as possible over the drier portions. At first I was of opinion that more moorum than that usually allowed for hand consolidation would be required in consolidating by the steam roller, in consequence of the losses above referred to, but subsequent experience has shown that with care and proper management the usual quantity is ample, or even less than the ordinary quantity, say one-fifth the volume of the metal might suffice if the rolling is done in rainy weather without artificial watering. The quality of the binding material requires more particular selection than in the case of a hand made road. In European examples I find fine sharp sand is recommended; this, although it would undoubtedly be the best so far as the roller is concerned, would be objectionable in a hot and dry climate such as India; pure dèbris of rock should alone be used, very particular attention being paid to its being perfectly free from earthy or

clayey particles, as any small admixture of these renders it almost impossible to roll down, from its sticking and clogging on the rollers and necessitating great quantities of water to wash away the impurities.

During the course of the work a number of different experiments were tried as to the best methods of proceeding with this work It has been found best to roll down the metal two or three times, in the 1st instance dry and without moorum, this has the effect of compressing the road together and turning the angles of the stones downwards, leaving flat surfaces; about one-third of the moorum should now be laid down and well watered, if sufficient water be not added, the binding will adhere to the rollers and bring up large patches of metal with it, tearing up the road and rendering it exceedingly difficult to manage afterwards, it has been found that the proper point of saturation is only reached when the water will lie on the road forming a kind of banked up ridge in front of the rollers as they move over it. Far greater economy will be effected by an unsparing use of water than by suffering the delays and inconveniences due to a pasty and sticky condition of the moorum. Watering, therefore, must form in a dry season a considerable item of the expense of consolidation by the steam roller, this charge has not been experienced to so great a degree in England, owing to the naturally moist climate, the use of fine sharp sand for binding, and the fact that the operations hitherto carried on having been in or on the outskirts of towns, a supply of water from the mains is both easy and comparatively inexpensive. After the first instalment of moorum is laid the remainder is added at those points where it has been washed in or towards the sides of the road, and the watering is plentifully carried on until an average of six or seven rollings completes the consolidation; should water be difficult to procure in proper quantities after three or four rollings, rather harm than good will ensue if the rolling be continued dry; nothing, therefore, in this case can be done, but either to procure the necessary quantity of water, or to finish the work by hand labor; the previous three or four rollings and the consequent well compressed state of the metal renders this a comparatively easy matter. Regarding the question of water, it must not be forgotten that in ramming metal by hand, a quantity per given length equal to that required by the roller may be requisite, but it is needed in small quantities extending over a long time. No greater absolute quantity may be required by the steam roller, but she needs it in large quantities for a short time;

thus, taking the quantity of water necessary to be supplied in one hour to a gang of hand-rammers, the amount to be supplied to the road in front of the steam roller in the same time will be as much greater as the speed of the machine is greater than the speed at which the gang of rammers will advance, or as, say, two miles to fifty feet, or thereabouts, or over 200 times as much water in the same time; the total quantity of water used in both cases remaining the same.

In a dry season, therefore, the supply of water becomes a very important item. This year two ordinary watering carts (such as used for watering station roads) were employed, but proved to be quite insufficient for the duty required, both as to capacity and facility of movement on newly laid metal; a greater number constructed so as not to require turning would undoubtedly prove of service and better in every way than watering by hand, and should certainly be provided next year. On an important road, where it was desired for several years to consolidate the maximum length capable of being done by the roller in one season, a traction engine and pump for watering purposes, as suggested by Mr. Davidson in his report, would prove as much a necessity as an economy. A sun awning with purdahs more completely shutting in the sides of the roller should be provided for future work, together with the minor alterations suggested in Mr Davidson's report. In order to provide better against the sickness which the arduous nature of the work in the most unhealthy season of the year entails, all the Native engine establishment should be supplied with tarpaulins or some good waterproof coverings. The provision also of some kind of moveable habitation for these men, would also add much to the effective number of working hours, preventing the necessity of their having to go at night, often many miles, to the nearest shelter The steering of the roller being a work requiring some skill and practice it will be advisable to instruct as many of the Native establishment as possible, so as to provide substitutes in case of sickness. This season frequent trouble and delay was caused by steersmen becoming sick just when they had begun to steer properly.

G. W. MacG.

Report by J. Y. DAVIDSON, ESQ, *Assistant Engineer, Kamthi.*

The Steam Road Roller which has been at work on the Northern road during the past monsoon is one of two which arrived in the Division last year, both having been made by Messrs. Aveling and Porter.

This Roller is 6-horse-power nominal with a boiler of the "Locomotive type." The cylinder is on the top of the boiler, the connecting rod working on to a crank shaft with a pinion on one end working a second motion shaft, this shaft again communicating with the axle of the front rollers by a pitched chain, the result of this combination being 20 revolutions of the engine to 1 revolution of the front rollers. The trailing rollers carry a turn-table over which the framing of the engine is placed, this arrangement enables them to be turned by a steering wheel attached to the turntable.

Holes are provided in the front roller for spikes which extend four inches radially, and are fastened by nuts on the inside. The Feed pump is supported on an overhanging bracket cast, on the bracket of the second motion shaft a coal box or bunker is supplied capable of holding three maunds of coal (English.) The total width covered by all rollers is 6 feet.

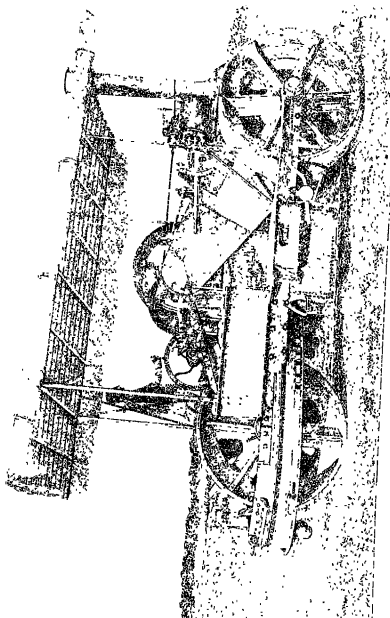
A detailed description of the whole machine is unnecessary, and without drawings would be unintelligible, the* Photographs taken some months ago show the general design. As however, the above named parts of the engine must be frequently alluded to in this report, I have attempted a slight description of them.

The roller was erected on the North bank of the Kanhán, $10\frac{1}{4}$ miles from Nagpur, and early in June was sent to Korai on the 58th mile, to await the commencement of the working season. No difficulty or accident of any kind was experienced during this journey. The waggon made in the workshop of the division was drawn by bullocks for the first 13 miles. The road for the greater part of that distance being of soft kunker metal.

The total weight at starting from the village of Amri, on the 14th mile was :—

	Tons	Cwt.
Weight of roller, ...	15	0
Do. of waggon, ...	1	10
Do of coal, ...	1	10
Stores, scales and tools (about)	0	8
Total about ...	18	8

* *Vide* Frontispiece and Plate XVI.

METAL CONSOLIDATION BY STEAM ROLLERS.

The heaviest incline to be ascended, travelling in a Northerly direction is at Munser on 26th mile, which is 1 in 19, the 27 and 28 miles are comparatively level, and the 30th and 31st have inclines varying from 1-30 to 1-16, this latter being a descending one going northerly.

The actual rolling work began on July 19th, during that and the two previous days so much rain fell that very few of the people would work; about a quarter of a mile of metal had been spread, and on this I thought it better to begin rolling, although we had few people to continue the spreading.

After passing the roller four times over each part of the road, the metal was found thoroughly compressed, and no good results were perceptible after a fifth trial,—I have no means of accurately judging the quantity of rain that fell from 2-45 P. M., when we began rolling, until 4 P. M., when we left the roller for the night, but as it was heavy even for the monsoon season it may be taken at 1 inch.

The next morning the heavy rain still continuing no coolies were at work, it was determined to try the picking up spikes.

The wooden plugs in the spike-holes some of which were put in in England, and some here during the hot weather, were expanded by the rain, so that the greatest difficulty was found in getting them out, after about 2 hours work the spikes were in and the picking up commenced: the wooden plugs have not been used since, the work being done equally well without them.

I then found from actual experience that, as I had expected, the wet weather is not the best for picking, for two reasons; the ground does not crack sufficiently, and the holes are filled up by the pressure of the trailing rollers passing over them.

After a short time it was found that the coolies employed on the engine were quite unfit for work, on account of the long exposure to heavy rain, and some of the wood which had been stored in the wagon saturated to such an extent as to render it almost impossible to keep steam.

Various circumstances quite unconnected with the roller delayed the work, so that it was the end of the month before this mile was finished.

Scarcity of coolies caused by the demand for field labor, heavy r

and feast days, are some of the difficulties met with at first starting.

On 23rd July, the first quarter mile was topped with moorum, and early on the morning of 24th was rolled again during a tolerable heavy shower;

a few women were employed with the ordinary country "Gurrahs" to throw water on where the topping was liable to stick to the rollers After going twice over the road it was found to be perfectly consolidated; this with previous rolling made six times the road was rolled.

The remainder of this mile was finished without any artificial watering, and has remained in excellent order ever since.

I have submitted the details of these, the first few days work, at some length, as they were the only days that we had seasonable weather. From 28th July until the 6th September we had no rain, and you ordered the work on the other miles to be finished by hand.

The dry weather experienced in the months of August and September has been a cause of great additional expense and labor, so great had the scarcity of water become in the latter month that it was only with difficulty enough could be got for the engine: there is, however, little doubt that more experience has been gained and more reliable data arrived at, than if the monsoon had continued without intermission, when difficulties arising from scarcity of water would not have presented themselves.

Four kinds of fuel were used during the season viz., Wood, Chanda coal, Chhindwara coal, English (Hartley steam) coal.

The details of the average working with each of these kinds of fuel with the number of miles on which accurate record was kept by each kind may be stated as follows:—

Table of consumption of Fuel.

TABLE I.

Description of Fuel	Number of miles	Number of times travelled over	Average per mile finished	1 mile once rolled	Stock price per Maund	Cost of fuel 1 mile rolled once
			MAUNDS	MAUNDS.	RS. A. P.	RS. A. P.
Wood, ..	5	6	46·1	7 68	0 6 0	2 14 1
COAL: Chhindwara,	4	4	30·6	7·65	1 4 0	9 9 0
COAL: Chanda, ..	3	4	15 2	3·8	1 4 0	4 12 0
COAL: English, ..	2½	6	11·0	1·83	2 2 0	3 14 4

In the last column the cost is shown of rolling a mile once, which with

a roller 6 feet wide on a 12 foot road equals two miles actually travelled. I think this will give more reliable data than taking a mile actually consolidated which will always be affected by a variety of circumstances such as the state of the weather, and the nature of the foundation of the road. The prices given are those at which the different kinds of fuel stand in the stock books of the division, and are rather higher than the market rates. If wood had been bought at the villages on the road and used as required, the cost would have been 4 instead of 6 annas per maund.

Of the 16 miles operated on, five miles had a 4-inch coat and eleven had a 3-inch coat of metal equal to 2,783-100 cubic feet, and the expenditure up to the 1st October was Rs. 1,142 for spreading and incidental expenses, or an average of Rs. 0-6-6 per 100 cubic feet From this and the Table of consumption of fuel given above, allowing one mile per day to be rolled six times, and adding Rs. 5 for engine expenses, we get a comparison of cost of steam and hand labor.—

TABLE II.

	Total engine expenses per mile			Per 100 cubic feet			Spreading of 100 cubic feet			Total per 100 cubic feet		
	RS	A	P.	RS	A	P	RS	A.	P.	RS.	A	P.
1 Mile with wood, ...	22	4	6	0	2	0	0	6	6	0	8	6
Chhindwara coal, ...	62	6	0	0	5	8	0	6	6	0	12	2
Chanda coal, ...	33	8	0	0	3	1	0	6	6	0	9	7
English coal, ...	28	6	0	0	2	7	0	6	6	0	9	1
If wood had been brought as required,	16	8	4	0	1	6	0	6	6	0	8	0

The rate for consolidation by hand in this division had never been under Rs 1-8-0, including keeping the road in repair for two months.

The results are independent of any expense for taking the roller from Kamthi to Korai and back again, and also for going over intermediate distances, as such expenses will always vary, and if taken into account in a record of experiments would give a fallacious result. As an example, on August 20th nine miles from Deolapar to Chorbowlie were travelled in 5 hours with 14 maunds of wood, being at the rate of one maund 22 seers per mile. The speed was two miles per hour and half an hour was due to a stoppage for water. The difference of levels being 166 feet

I would, however, state that these results must not be taken as the best that may possibly be obtained from the country coal, especially the Chanda coal, which if fired and treated *like* English coal gives but a poor result. When first tried in the roller on fresh metal it was only with the greatest difficulty, and with frequent stoppages that steam could be kept up at all, the fire bars were then placed wider apart, the ash pan removed, and the blast cock kept open, the result was a saving of 25 per cent. in the consumption, an indirect but considerable saving was also effected in time in getting up steam. With fire bars arranged as for home work, the time required for this work was nearly $1\frac{1}{2}$ hour, but when altered as stated $\frac{3}{4}$ of an hour was enough; on one occasion I timed it and the pointer of the Gauge moved from lbs. 20 to 50 lbs in $2\frac{1}{2}$ minutes. From this I have little doubt but that more experience with this coal would enable us to considerably reduce the difference in performance between it and English coal.

The Chhindwara coal is not in many ways so difficult to manage as the Chanda, but its liability to clinker is its great fault; any required degree of heat can however be obtained at first, but it is found that as more fuel is added the heat is diminished and steam goes down, on account of the thick clinker on the bars and which requires considerable force to remove it.

With the exception of a few pieces here and there all the road was picked up by the Roller. The way in which this is done by the spikes, already alluded to, is most effective and simple, starting from a given point, say a mile stone, and making two double trips, that is going twice up and twice down, the whole surface of the road 12 feet wide, is completely broken up and might be easily dug up with a spade.

This operation, however, requires great care both from driver and steersman, the former must have plenty of steam and open and shut his regulator as the spikes get on hard or soft places, and meet with greater or less resistance. If this is not attended to, and the engine allowed to run, a great strain and sudden jerks will be thrown on the working parts which is not advisable. Even with very careful driving this is unavoidable to a certain extent, but all danger is avoided by care.

On accurate steering also a great deal depends, more even than in rolling, as the spikes have a tendency to throw the roller slightly to one side. If this is not quickly counteracted, the holes in the road become

irregular, or in other words part of the road remains unbroken. Altogether picking up is hard work for the engine and the people employed on her, especially when breaking ground for the first time and in warm weather. In some places where the road is harder than usual the spikes scarcely enter the ground at all at first, and this is the time of greatest trial, each successive trip becoming easier and easier until the whole is broken up.

The indirect saving effected by this operation will I think be greater than can be shown at first, but I have little doubt you will find the benefit to the road is in indirect proportion to the honest work of the steam roller, compared with the "scamped," and uncertain work of coolies.

Comparison of cost of picking by hand and steam labor.

			RS.	AS	P	
100 coolies @ $2\frac{1}{2}$ annas per day, will pick up about a mile,			15	7	0	
Roller	For wages and stores ½ day, men, picking after the roller,	6-8-0				
	Wood, fuel, @ 6 annas per maund, roller travelling 4 miles lineal,	5-12-2				
			12	4	2	
	Balance in favor of engine picking,		3	2	10	per mile.

This is supposing that each cooly does over 50 feet, and the roller only picks up at the rate of 2 miles per day, which is as much as it is advisable to pick up at one time.

On the morning of 5th September I had a quarter of a mile measured off on 27th mile, where the road passes close to the tank at Kandrie, with the intention of ascertaining the exact cost of artificially watering, and at the same time making a thoroughly good road. For this purpose 16 women at 7 pice per day, and 7 men were employed with 21 gurrahs, and the time occupied was 5 hours.

This delay was principally due to the fact that only two men can put water on at once with good effect, when the engine arrives at a place where very little has been thrown down, it must stop for a time, or go back some distance; the latter is the better course as the steam is used instead of being wasted.

Speed on the level is 2 miles per hour

5 hours $\times$ 2 = 10 miles distance due time.

10 $\times$ 4 = 40 quarter miles lineal.

$\frac{40}{2}$ = 20 times over whole road.

As we know that with plenty of rain, as on the 57th mile, six times is enough, the roller travelled on this occasion $\frac{20}{6} = 3\ 334$ times more than necessary, and consumed therefore 3 334 times more fuel than was required If we take the present Bazar rate of wood, viz, 4 maunds per rupee as a standard, we have the following data —

Six times over whole road for one-fourth of a mile = $1\frac{1}{2}$ mile lineal.

Fuel 7 69 maunds per mile, @ 4 maunds per Re. = 11·52 maunds = Rs. 2·88 per $\frac{1}{4}$ mile.

= 2 88 Rupees for one quarter mile finished without hand watering.
2·88 Rupees × 3 334 = Rs. 9 6 per $\frac{1}{4}$ mile finished by hand watering.
9·6 − 2 88 = Rs 6 72 excess per $\frac{1}{4}$ mile finished, 6 72 × 4 = 26 88 excess per mile for fuel That is at the rate of Rupees 27 nearly per mile for fuel, more when hand watering than when watering from rain fall.

Independently of expense there is the time taken up; a most important consideration when the short working season is considered.

A length of road on the 25th mile was picked up, spread and rolled with water, in the presence of Chief Engineer and yourself; as this was done purely for experimental purposes it cannot well be taken in comparison of cost.

Water in rivers running at right angles to the road must I submit be looked upon as utterly useless for consolidation by a steam roller with our present appliances. I tried the experiment on the 41st mile, but the result was so extravagant that in a very short time we stopped and put the people on to other work.

Under any circumstances, one great objection to hand watering is the danger to the people employed. The necessity for giving a curved surface to the road, makes it advisable to have the water thrown on as close to the roller as possible To do this a man must walk backwards at the rate of two miles an hour within a foot or two of the roller; should he slip the consequences would probably be serious. Further most of the water runs to waste, the work has to be done quickly and is unsuited to cooly labor, and could not be safely carried out at all unless under the supervision of Engineers or skilled European subordinates.

The two water carts with iron tanks fitted with $1\frac{1}{2}''$ pipes of the usual pattern were sent up, and tried on the 45th mile; but the water being very dirty the pipes were soon choked, and had to be discontinued for the

time. On the 41st mile they were tried again with slightly better results, as the water was clearer, in other ways the result was not satisfactory. Their weight when full of water is too much for an ordinary pair of bullocks on fresh metal, who, try to go on the earthen sides of the road where the resistance is less, or if prevented from doing that lie down on the road. Half filled carts were tried, but with little better success. The necessity for turning round frequently, the obstinacy of the bullocks made worse by their fear of the engine, rendered the whole proceeding nearly useless

Having endeavoured to show the extra cost of watering by hand labor under the most favourable circumstances, and the impractibility of watering with an ordinary water cart, it is perhaps unnecessary to point out the difficulty, with our present appliances, of using water at any considerable distance from the road. The question then arises, is "Steam Rolling" unsatisfactory on the Northern Road except on a wet day ? I think not with water carts, which could be made up in the workshops of the Division, and drawn by a 4 horse-power traction engine: even in a dry season like the past, at many places along the road, water in sufficient quantities can be obtained to keep the roller at work and at her full speed. It would be necessary to make the carts so that they could be drawn in either direction, turning on a narrow newly metalled road being undesirable. An engine if fitted with a pump, could fill the carts if the water was 100 feet from the road side or from a stream 20 feet below. During wet weather, water in abundance can be had within less distances than these, and should there have been no rain for a day or two, the ground would be sufficiently hard to enable the Traction engine to leave the carts, go any distance from the road, and fill the carts through a hose; or pump the water on to the road direct, according to circumstances.

An engine of this sort could be used for general work as a portable engine for driving pumps, or as an ordinary traction engine, during the rest of the year. It could also be employed in transporting the coal for the use of the roller before the monsoon season, with more certainty than can be done with country carts which frequently break down, and lose a considerable part of their loads. I may be permitted to say, in concluding this part of the subject, that much better results would have been obtained, and a considerable sum of money saved to the Government of India, if, in their numerous notices and circulars, the makers of these

machines had given some hints, however vague, of the quantity of water required for consolidation purposes. The use of these machines is quite new even at home, and when I was ordered to watch the performances of this one and report upon it, I sought in vain for any information on this most important point. In the published copy of Mr. Avelings' paper read at the society of mechanical Engineers this year, the subject is only casually mentioned although the other operations are accurately described.

When the steam Roller returned to Kamthi, the rollers and other heavy portions were disconnected and wagon wheels having been placed under the boiler and engine it was brought over the temporary Bridge into the Kanhán workshops for examination, repairs, and painting; this last being greatly needed, some of the parts having rusted considerably.

With a few exceptions she is well adapted for work. The awning or cover shown in the Drawing is not large enough, it ought to be wider, and longer, with curtains at the sides to keep sun and rain off the men without interfering with their movements.

The engine itself is strong and well proportioned and, as might be expected, shows no symptoms of wear as yet. The original spur wheel for the second motion shaft was broken in the voyage out. The one now in use was cast in Bombay and is not very well adapted for its work; the teeth are not suitable for those of the pinion, consequently both have worn considerably and more than should be for one season's work; it is possible that both wheel and pinion may work for another season, but a safer way would be to get a new one from Messrs. Aveling and Porter before the monsoon. The bearings of both sets of rollers ought to have been fitted with brasses and better means of lubrication given. The front ones especially have worn down considerably into the white metal, so that the axle has been rubbing on the cast-iron saddle on which the bearings are cast. This can, however, be remedied for next season's work, after which brasses should I think be fitted.

The steering gear is hardly adapted for natives, and will I fear be a constant source of trouble for some seasons to come. It is not hard work for a European in a moderate climate, but requires a quickness of eye and hand combined with close attention, which it is difficult to find in the ordinary native. In an unhealthy season and on a road surrounded by dense jungle, like the Northern, the work is particularly trying; four steersmen were rendered unfit for work by fever in the first weeks of the

season, and others after they had been taught and could manage to steer tolerably well, refused to remain although paid much more than they could get elsewhere.

In future engines an alteration in the position of the fire door would be advisable. This would enable a man to attend to the fire without interfering with the driver, who could then have all his attention directed to the engine and be ready at any time to stop and reverse when required. This would be even more necessary were the speed of the rollers increased to 3 miles an hour as purposed by Mr O'Callaghan last year. In case of the roller leaving the road while going at that speed, the consequences might be serious if on high embankments, &c.

A cock on the feed pipe close to the boiler is necessary, on this as on other engines at work in this Division where the water is impregnated with lime and other impurities: the cock should be made so that it can be used in three ways, viz., (1st), To shut off from the boiler and allow the feed valves to be taken out when steam is up; (2nd), To allow the water to be blown out of the boiler to clean the inlet, (3rd), When shut and the pump started to allow the cold water to escape and not burst the pump or pipes. When the feed pipe was lately taken off it was found that the hole was reduced to about half its proper area by incrustation.

The means of access to pitched chain for driving is inconvenient and would be greatly improved if the top part of the casing could be easily taken off and larger oil holes drilled in the links; only a few links can be cleaned and oiled at one time, the engine has then to be moved and the operation repeated; with a casing made as suggested above, about one-third of the chain might be exposed at a time and the work of cleaning, &c., more carefully examined. The boiler is well proportioned and being fitted with a man hole in the smoke box is capable of being easily cleaned and examined. The foot plate should be widened about 12" on each side. This I consider, almost a necessity for this climate.

The position of the feed pump might also be altered with advantage. The bracket on which it is now placed springs perceptibly at every stroke; if from bad packing or any other cause, the plunger met with undue resistance, the bracket would be extremely liable to break off. A pump bolted on the boiler direct would be much safer.

Priming frequently occurs when going up gradients with the trailing rollers first. It is just possible that the designers never intended their

machine to work in this way; it is, however, absolutely necessary on our roads, (only 12 feet wide as regards metal,) and the difficulty only requires to be brought to their notice to be remedied in future engines. A larger smoke box would be an advantage; when working heavy gradients, the present one gets up to such high temperature as to endanger the lagging, and in one case this was set on fire. The chimney should be of wrought-iron, and not as at present of thin cast-iron, which is liable to be broken in many ways where a wrought-iron one would be safe.

Besides the above, there are a few minor matters which would contribute greatly to the efficiency of similar machines and some of which might be advantageously applied to the one now in use; for instance; (1), A scraper on each side of the driving rollers; (2), Steel instead of iron picking up spikes; (3), Clutch gear instead of the straps and buckle for holding the pinion in or out of gear; (4), Brass brushes for the driving roller bearings; (5), The small rollers for supporting and guiding trailing rollers, put in more accessible or convenient positions; (6), A blast cock which can be regulated from the foot plate.

A movable hut for the accommodation of the natives employed would be extremely useful, the frame work and wheels only would require to be strong. The upper part of galvanized iron with little or nothing of internal fittings would be quite sufficient for their simple habits.

A considerable saving would accrue from a hut like this, when it is necessary to stop the engine for the night several miles from a village in a district known or supposed to be haunted by wild beasts. In such cases the men not unnaturally like to reach a place of safety before dark, and they leave their work unless well watched, a considerable time before they should do so.

For a similar reason, it is difficult to get up steam in the morning at an early hour: if the workpeople and firemen were hutted within a few yards of their work, the time available for rolling would be on an average two hours a day more than at present, and this nearly equals a quarter of a mile consolidated.

A saving in wages of night watchmen would also be effected, two of whom are now required.

Some of the proposals and remarks which I have made above may appear unimportant and superfluous at first, but when it is considered, that like all operations where machinery is concerned, the whole is only a

succession of details, the failure of any one of which seriously affect results, my suggestions will I hope be approved.

Appendix by G. W. MacGeorge, *Executive Engineer, Kanhán Division.*

In accordance with your verbal instructions, before being brought into Kamthi the steam road roller was tried on a short length of road laid with kunker metal on the 16th mile between Kamthi and Doomrie. The length laid down was a little over 1,000 feet in length, and the thickness of the coat of kunkur 4 inches resting on an old kunker road. I personally inspected the whole of this operation, and I am of opinion that the results, although satisfactory, were not so much so in this case as when stone metal is employed The metal used was that small hard field kunker found in generally *round* nodules averaging not more than an inch in diameter. The effect of passing the heavy roller dry over this metal was to bank it up considerably in front of the rollers, so much so as to render it at first very difficult to proceed, and the road afterwards somewhat uneven. After four rollings the pieces of kunker sufficiently hard to resist crushing were, owing to their round form, completely unbound. I then laid down moorum and well watered the road and repassed the roller over the length some seven or eight times, when, as the road appeared to be smooth and hard, the experiment ceased. A few days afterwards I found some portions had been cut up by the narrow wheeled traffic, but the general state of the metal was satisfactory; it has since required occasional looking after. I do not consider the experiment as in any way conclusive, as regards any decided inferiority of kunker used under the steam road roller, as compared with limestone or granite metal, as I think that in the experiment referred to the kunker was too small and round; had pit kunker been used in large nodules I have no doubt that the roller would consolidate it rapidly and well.

Close to Munser a short length (about 100 feet) of the road was laid down with fine river sand as a binding material; this portion has remained in very good order ever since, and particular attention will be given to observe its effect under the hot weather; the employment of sharp sand from its not sticking to the rollers, is a great point in its favor.

As regards the state of the whole number of miles of metal rolled this

season at the date of writing: From Doomrie to the 29th mile it has remained in very good order; the 30th mile has given some extra trouble which I attribute to the circumstance that most of this mile was picked up by hand, in order that the roller might commence rolling directly she arrived from Deolapar; the 41st and 42nd miles, the 45th and 49th are good, and the 57th particularly so; altogether, comparing these miles with others done in other parts of the Division by hand labor, I think there can be no question that they are better (with the exception of the 30th mile), and require less repairs. After the hot season I confidently anticipate that the state of these miles will more fully show all the benefit they have received from the weight of the roller, and that they will last longer than those done by hand-ramming.

Note by Offg. Chief Engineer. T. W. ARMSTRONG, ESQ., M. INS. C.E.

Nagpore, 1st June, 1871.

The Reports submitted by Mr. MacGeorge, Executive Engineer, and Mr. Davidson, Assistant Engineer, on the above operations, are so full, clear, and detailed, that I find I have hardly anything to add to them by way of explanation.

The question of consolidating metal by steam power is so important, that I do not hesitate to give the Engineer's reports in full.

In the opinions expressed I concur generally, except that in cases where water is scarce, and the rains scanty and intermittent, it will be best, I am confident, to roll the metal at first without any topping: and after this, to spread the moorum or gravel, and finish off by hand labor, four or five rollings should suffice.

This system is to be tried this year, and I believe the results will be both satisfactory and economical.

It is very troublesome and tedious attempting to finish by rolling, when the topping is not what is termed *slushed* with water. In the absence of rain, a scanty supply of water renders the moorum or gravel topping sticky and greasy, it is then licked up in large patches by the rollers with masses of metal adhering; this in a way destroys the consolidation effected before the topping was laid on. I do not think sand is fit for topping in this climate.

I have already reported that I do not consider a steam roller suited for laying down first coats of metal on the fresh clay banks of a new road;

nor would it be a useful machine on a road which was not bridged generally. If the roller was brought for work to a road, whose intersecting rivers and nullahs were unbridged, and the more numerous such gaps the more the delay and trouble, it would have to be taken to pieces at almost all of these breaks, unless temporary tracks were constructed across the beds; and if the rivers held deep water, shipping and unshipping the machine, even when in pieces, is a slow process requiring careful supervision.

These rollers are not, as I state, very suitable for consolidating first coats of metal. If this were attempted in the monsoon season, at any rate in this part of India, they would sink into the fresh banks of earth and simply stick then and there,—on old embankments, consolidated some time, this evil would be felt less, but even on these, unless in comparatively dry weather, delays and sinkings would be frequent.

Once a first coat of metal is laid, then for all successive layers the rollers can be used, and I consider with considerable economy, much saving in time, and sound honest work as the result.

The Executive Engineer, in his report, shows the saving by steam rolling to be Rs. 143-9-0 per mile, under rather adverse circumstances, which he explains. He states also that when circumstances are favorable, the saving effected amounts to Rs. 190-13-0 per mile over hand consolidation, and from these data he calculates that the steam roller recoups her original cost after consolidating 60 miles of metal, taking the average saving to be Rs. 160 per mile. This is a moderate and a safe calculation in my opinion.

For certain reasons, not necessary here to explain, English, Chhindwara, and Chanda coal were used for firing as well as wood. This has unavoidably run up the mileage rate for consolidation. The Executive Engineer however shows that if only wood had been used, Rs. 29 per mile would have been gained, bringing up the general saving per mile over hand labor from Rs. 143-9-0 to Rs. 172-9-0.

When consolidation by the roller is carried out during sufficient rainfall, the Executive Engineer in his report (*vide* Table C.,) states that a saving of over Rs. 200 per mile may be obtained over the cost of hand labor.

Picking up the road before laying down the new metal is an indispensable operation. It is fully explained both in the Executive Engineer's and in Mr. Davidson's report, that a gain of Rs. 3-2-10 per mile is

effected by the roller, or as Rs. 15-7-0 (the cost of hand labor,) is to Rs. 12-4-2, (the expenditure with the engine).

The end of Mr. Davidson's report, is of much interest, it contains the opinions and proposals of a man who understands his work thoroughly, and who has taken great pains to carry out successfully and economically the duties entrusted to him.

I concur in all he states, and I recommend that a copy of his report be sent to the makers of the steam roller, Messrs. Aveling and Porter.

The "Appendix" by Mr MacGeorge gives information regarding the consolidation of some kunker metal by the roller; the result was favorable. I believe pit kunker can be as cheaply and solidly consolidated as stone metal; I can see no reason why this should not be so.

Remarks by MESSRS. AVELING & PORTER *on* MR. F. L. O'CALLAGHAN'S *Report and Suggestions.**

Respecting the awning mentioned in para. 19, as being desirable to protect the driver and steersman from the sun, there is no difficulty in providing a simple and efficient one.

Para. 20, suggests that the rollers should draw behind them a supply of fuel for one day's consumption and carry in their bunkers sufficient for a run of two miles. The machines are already fitted with couplings for drawing wagons behind them, and a suitable one can be constructed at a cost of £45. The coal bunkers can be enlarged as desired without any inconvenience.

The foot plate can be made wider as proposed in para. 21 of the report.

Regarding the desired alteration in the speed gearing of the machines alluded to in para. 22, we shall take care that any future rollers ordered of us be arranged to travel at from 3 to 3½ miles per hour on good roads; this is a higher speed than draught horses generally maintain; and beyond it we consider that it is not prudent to work such heavy machines on ordinary macadamised roads.

Para. 23 advocates the substitution of double for single cylinder engine and the removal of the existing fly wheel In considering these recommendations we incline to believe that a little longer acquaintance

* *Vide*, P. P First Series, Vol. VII, page 115.

with the present rollers would modify the Engineer's opinion of the relative value of the two kinds of engines. We have found in the course of a long experience in the use and construction of engines for common roads, that single cylinder locomotives are much more economical, more powerful, less complicated and consequently less liable to get out of repair than are double cylinder engines. It is also to be observed that after 2 or 3 day's practice single cylinder engines can be handled as easily as double cylinder engines

The remarks, it must be added, apply chiefly to engines of small power, such as are those that drive our 15 ton rollers, to these it would be difficult to apply two cylinders and retain at the same time the simplicity and strength of the existing gearing. To larger engines there would not be attached the same inconveniences in the use of double cylinder gearing.

The fly wheel, to which objection is taken, can easily be so covered in as no longer to prove the danger to horses it is now alleged to be. It should be borne in mind that its removal would diminish the general usefulness of the Engine, inasmuch as without it the Roller cannot be used as a stationary engine for driving, pumping, sawing, stone breaking, or other machinery, and for which it is now properly adapted.

If the engines be made of greater horse-power, as suggested in para. 24, the rollers should also be made larger in diameter, say 6 feet in place of 5 feet as now constructed. This alteration would materially reduce their liability to sink into newly made roads.

The inconvenience pointed out in *para.* 25, arising from the present construction of the ash-pan, shall be remedied in future.

In conclusion, we would add that it will be our study in the event of receiving further orders from you, to entertain, and whenever practicable, carry out any suggestion from the Engineer in charge of the Rollers, tending to the improvement in their design or convenient alteration in details of construction.

No. XXIV.

ON THE MOVEMENT OF WATER IN PIPES, CANALS AND RIVERS.

Adapted from articles in the "Ponts et Chaussées." BY LIEUT. W. G. ROSS, R.E.

I. Dubuat established two principles, which have up to the present time served as the basis of research in all enquiros into the laws of the movements of water in canals and rivers. These two principles are—

1. The moving force, which each of the molecules of water that compose a river has, arises only from the surface slope.
2. When water moves uniformly the resistance it meets is equal to the accelerating force.

He further established that these retarding forces which make the motion of the water uniform are independent of the pressure. If then the action of these forces is to be attributed to the nature of the bed they cannot be exactly compared to the friction that takes place between solid bodies; they should be considered as of the same order but of an essentially different nature.

Dubuat's general formula for flow of water in all channels is

$$V = \frac{297 (\sqrt{r} - 0{\cdot}1)}{\sqrt{s} - \log \sqrt{s + 1{\cdot}6}} - 0{\cdot}3 (\sqrt{r} - 0{\cdot}1)$$

in which

V = mean velocity *in inches* per second.

r = mean radius or hydraulic mean depth = $\frac{\text{area of water section}}{\text{wetted perimeter.}}$

$\frac{1}{s}$ = the slope.

The unit of length is the inch.

Irrespective of the practical difficulties that attend the employment of this formula it was soon discovered to be insufficient to represent the law of water-flow.

II. M. de Prony starting with Dubuat's principles, and observed facts, endeavored to establish another formula.

He assumes that the nature of "lining," or surface of the bed of a water conduit has no influence on its flow, and that the movement is produced by very thin strata of water, such strata being parallel to the slope of the bed and of an uniform velocity. The formula put forward by him was

$$A\, i = \chi f(v)$$

where

A = area of section.
i = slope or fall in unity.
χ = wetted perimeter.
v = velocity at the bed or bottom.

Making $\frac{A}{\chi} = R$, and expanding $f(v)$ according to the first powers of the variable, which again he replaced by the variable U, he obtained the equations

$$RI = a\,U + b\,U^2$$

the co-efficients "a" and "b" being determined from a certain number of experiments of Dubuat's by the method of mean squares. M. de Prony did not delude himself as to the scientific value of his formula. He had admitted with Dubuat that the mean velocity was a function of the bottom velocity quite independent of the dimensions and slope of the canal. "However," says he, "it is difficult to persuade oneself that these various elements have no influence on the relations between the bottom, mean, and surface velocities "Mais il fallait pourvoir aux besoins de la pratique" (Recherches sur la Théorie des eaux Courantes, 143.)

Everything on the subject of the employment of the formula of M. de Prony and of Eytelwein (the formula of the latter is that of the former in another form) that can be said, has been said by MM. Darcy, Dupuit and Bazin. They have unanimously condemned it.

III. MM. Darcy and Bazin, after investigating experimentally the influence of the nature of the bed, attempted to resolve the problem by transforming the formula of de Prony, so that the co-efficients might

vary with the mean radius and the nature of the surface of the channel. The result of the researches of M. Bazin are given by Col. Anderson, R.E., in No. CXCVII. of the Professional Papers on Indian Engineering [First Series.] Co-efficients varying with both these elements at one and the same time are however unsatisfactory; they are, in a way, evident proofs that the general formula does not apply to the nature of facts. M. Gauchler, an engineer of the Ponts et Chaussées, on taking this into consideration was induced to believe that there must exist some simple algebraic relation containing only one co-efficient affecting the mean radius and variable with the nature of the bed, which should represent the phenomenon of the movement of water under every condition The method adopted was synthetical, and extended over a long period of searching experiments.

IV. M. Gauchler, acting under the advice of M. Dupuit, worked on the experiments recorded by M. Darcy at Challot. These experiments were on pipes, and they were carried out under many and various conditions of diameter, slope, and nature of material. M. Darcy had proposed on the teaching of these experiments to modify M. de Prony's formula

$$RI = aU + bU^2$$

so as to make

$$a = \alpha + \frac{\beta}{R^2}$$

$$b = \alpha' + \frac{\beta'}{R}$$

α, α', β, β' varying with the nature of the channel. He also in order to do away with so many co-efficients proposed two other formulæ

$$RI = b_1U^2, \text{ and } RI = a_1U$$

the second being employed only for all velocities less than 0·328 feet per second. In these formulæ b and a are variables and functions of R Hence he has in these formulæ given to b_1 the form

$$b_1 = \alpha + \frac{\beta}{R}$$

and in searching for values of α and β applicable to pipes whose channels are covered with deposits (depots) M. Darcy has evolved the following

$$b_1 = 0{\cdot}00051 + \frac{0{\cdot}0000065}{R}$$

As however these experiments were all made on pipes whose diameter

was never greater than 0 80 feet, they cannot be used for calculations of discharge in pipes whose diameter is higher, the more especially as the formulæ of Darcy, although unlike the formula of De Prony in being based on a larger number of experiments, are similar to these in being not the less deduced from a preconceived formula, the co-efficients of which have been applied by interpolation to the experiments giving the formulæ of Darcy.

V. The system adopted by M. Gauchler was to study in great detail pipes of the same diameter and material under various conditions of velocities and slopes, and then keeping the slope constant to study the velocities and diameters under varying conditions. By these means he hoped to express the relation existing between these three terms by one general formula.

But he also approached the subject theoretically in the following manner:—As the action of the molecular re-actions was quite indefinite, he put this term aside and only took into consideration the movement of the centre of gravity of a molecular fluid. This movement being independent of the molecular reactions, it was clear that the nature of the material of the channel alone affected it. The retardatory force of the channel is due to its uneven surface, against which the molecules of the liquid impinge, and from which they rebound in opposite directions, as they are elastic. These molecules again act upon and retard others. The sum of resistances thus produced is similar, therefore, to the shock of a fluid vein against a plane normal to its direction.

If the asperities of the channel are equally distributed over the wetted surface, and if the velocity at the channel is parallel to the axis of the pipe, the sum of the resistances is evidently proportional to the surface wetted, and to an unknown function of the velocity at the surface of the pipe. This velocity M Gauchler admits, as did de Prony, to be a function of the mean velocity independent of the diameter or slope.

Let D be the diameter of a pipe.

L its length.

V the mean velocity per second.

The resistance which such a section of the pipe opposes to flow can be expressed by

$$\pi \, D \, L f(v)$$

But this resistance is also equal to the impulse the liquid receives from

its weight and if to traverse L the liquid descended from a height H, the liquid would produce a shock measured by the expression

$$\tfrac{1}{4}\,\pi\,D^2\,v\,\sqrt{2gH}$$

$$\therefore\ \pi\,DL\,f(v) = \tfrac{1}{4}\,\pi D^2 v\,\sqrt{2gH}$$

Let us take the unit of time as one second. Let θ be the angle of the slope I, and L the length of pipe traversed in one second, then

$$L = v, \quad \text{and } H = v \sin\theta.$$

Substituting these values in preceding formula, and simplifying, we get

$$fv = \tfrac{1}{4}\,D\,\sqrt{2gv\sin\theta} \;\dots\dots\dots\dots\dots (a).$$

If θ is so small that we can substitute the tangent for the sine we can express equation (a) in the form

$$\frac{f(v)}{\sqrt{v}} = a\,D\,\sqrt{I} \;\dots\dots\dots\dots\dots\dots (1).$$

Such would be the law of the movement of water if the hypotheses were rigorously true. But it is evident they are not. The threads or veins of water in a pipe do not all flow parallel to the axis, but rebound from side to side, so that even if a channel of perfectly smooth surface could exist, these would always exist from this cause a retardation of flow.

VI. After vain efforts to express the first term of the last equation as a function of the second, M Gauchler was induced to try empirically the formula

$$\sqrt{v} = b\,\sqrt{D\sqrt{I}} \;\dots\dots\dots\dots\dots\dots (2).$$

considering the $\sqrt{v}$ in the denominator of 1st term of (1) as an indication that $f(v)$ might be irrational.

Using this expression to 56 experiments of Darcy's made with cast iron pipes, M. Gauchler was induced to modify it to

$$\sqrt{v} + a\,\sqrt[4]{v} = b\,\sqrt{D\sqrt{I}} \;\dots\dots\dots (3).$$

where a and b varied with the diameter. As it was necessary that b should only vary with the nature of surface of channel, he modified this further into

$$\sqrt{v} + D\,\sqrt[4]{v} = a\,\sqrt{D\sqrt{I}} \;\dots\dots\dots\dots (4).$$

It is unnecessary to reproduce all the experiments of M. Gauchler with this formula, and other modifications of it; they showed during investigation that he approached nearer and nearer the desired formula.

VII. An expression exact enough to resolve all cases of ordinary occurrence in practice was at last obtained. This was

$$\sqrt{v} + \tfrac{1}{4} D \sqrt[4]{v} = \alpha \sqrt[3]{D} \sqrt[4]{I} \ldots\ldots\ldots\ldots (A)$$

evidently the formula did not apply to very slight slopes As a fact owing to capillary action in every pipe the velocity becomes nothing before the slope is reduced to zero. The formula (A) may be more exactly expressed

$$\sqrt{v} + \tfrac{1}{4} D \sqrt[4]{v} = \alpha \sqrt[3]{D} \sqrt[4]{I - \beta} \ldots\ldots\ldots (B).$$

β representing the capillary attraction.

Now, Laplace has established that the force of capillary attraction acts inversely as the diameter, so if N be the force

$$N = \frac{m}{D}$$

m being a constant depending on the natures of the liquid and channel M. Gauchler determined a value of β which gave sufficiently accurate values for water

$$\beta = \frac{0\ 0000066}{D}.$$

This gives, it is said, very fair results.

As, in practice, velocities of 0 328 feet per second, or slopes gentle enough, and diameters small enough to enable β greatly to affect the value of I are rarely met with, β can be neglected

The formula to be used therefore is (A). M Gauchler with this formula went into a great many recorded experiments which it is unnecessary to transcribe. The results for iron pipes were eminently satisfactory. Those for pipes of sheet iron and bitumen are not so satisfactory. The explanation of this is that pipes of the latter materials became affected by the continual passage of water, and gave varying results. The temperatures at time of experiments also affected these pipes considerably. In lead pipes the most satisfactory and even results were given, when the velocity exceeded 1·64 feet per second. Water moving at this velocity seems to give lead a high polish. It is a curious fact that the value of α for glass pipes is not so high as that for lead. This was probably owing to the necessarily uncertain shape of the glass tubes; indeed an element of uncertainty is introduced into all the experiments by this and other con-

ditions under which the experiments were conducted. The pipes were ordinary cast-iron pipes except that the joinings were carefully made; the dimensions of each pipe were not constant; in those of slight slope and sluggish flow silt was constantly deposited, &c., &c. It is said that the formula very accurately for all practical purposes represents the flow of water in pipes.

It remains only to add a table embodying the results of M. Gaucher's investigations. If the co-efficient for pipes lined with silt be taken in calculating any problem of water supply, it is evident as a is here at its lowest that we shall always be on the safe side. For pipes of small diameter the term involving the 4th root of v can be neglected.

Formula $$\sqrt{v} + \frac{D}{4}\sqrt[4]{v} = a\sqrt[3]{D}\ \sqrt[4]{I.}$$

Description of channel.	No of experiments	Diameters of pipes in feet	Slope in unity, or one foot.	Value of α.
Cast-iron pipes (new), ..	40	0·27 feet to 1 64 feet	0 0002 feet to 0·17072 feet	6 625
Do do (old but clean),	16	0 802 feet to 0·974 feet	0 00028 feet to 0 11348 feet	6 1 to 6·3
Do do (lined with silt),	21	0 118 feet to 0 798 feet	0 00025 feet to 0 13981 feet	5 5
Sheet-iron and bitumen pipes,	41	0 088 feet to 0 935 feet	0 0002 feet to 0 30714 feet	7·0
Wrought iron pipes, ..	38	0 04 feet to 0·13 feet	0 00022 feet to 0·34426 feet	6·4
Lead pipes, ...	21	0 046 feet to 0·1345 feet	0·00044 feet to 0·16148 feet	7 0
Glass pipes, ...	6	0·163 feet	0 00096 feet to 0 11191 feet	6 7

The above formula is expressed in French mètres.

MOVEMENT OF WATER IN OPEN CANALS AND RIVERS.

I. We now come to the consideration of flow in open channels.

A very few years ago there existed few and very limited recorded experiments on the flow of water in canals and rivers; these, moreover, were inexact from various causes. These remarks apply to the experiments conducted in Germany by Brunnings, Woltmann, and Funck, to those of Dubuat, and in a less degree to those of Baumgarten, Emmery, and Léveillé. It became evident that the want must be supplied. A very careful series of experiments under the able direction of M Darcy and M. Bazin was put in hand about the year 1856. M. Darcy unfortunately died in 1858, and on M. Bazin fell the duty of finishing the work. In 1863 a committee of Engineers presented to the Académie des Sciences a report on these collated labors. This report has been translated by Colonel Anderson, R.E., and will be found in No. CXCVII., of the Professional Papers on Indian Engineering [First Series].

II. M. Gauchler takes these experiments of M. Bazin, and as before in the case of pipes, deduces a law of motions for canals and rivers. He bears testimony to the singular exactitude of these experiments.

At commencing M. Gauchler was induced to imagine that the law regulating the flow of water in open channels must vary considerably from that affecting flow in closed channels. M. Bazin had thought so also. M. Gauchler, however, in the course of his investigations, found that the laws of flow in closed and open channels were very similar, except that the latter were of a simpler character than the former.

III. He commenced by taking series of experiments of MM. Darcy and Bazin, in which the slope had been greater than 0·0007 in unity; he found the invariable law for the same channel, and for a constant lining of the channel was that the expression $\sqrt[3]{R}\ \sqrt[4]{I}$, (R and I being as before,) varied as the square roots of the mean velocities Thus taking the first of the series of experiments reported by MM. Darcy and Bazin which were carried out by M Baumgarten, he obtained the following very satisfactory results.

The correspondence between the figures in columns 5 and 6 is remarkable. It is to be observed that the numbers of the above recorded experiments are those of the Darcy-Bazin series. The experiments were

all carried out in the same portion of canal, and consequently the nature of the channel was the same in each.

1st Series.

No.	R.	I.	v.	$\sqrt{v}$	$7{\cdot}3 \times \sqrt[3]{R}\ \sqrt[4]{I}$
1	2	3	4	5	6
3	0·2158	0·029	3·428	1·850	1·810
4	0·1876	0 060	4·246	2 06	2 074
5	0 2686	0·0121	2 312	1·520	1·563
6	0 2545	0 014	2 549	1 549	1·591

M. Gauchler basing his hypothesis on the evident accord of columns 5 and 6 in above table, assumed as his touchstone for the other recorded experiments the formula

$$\sqrt{v} = a\ \sqrt[3]{R}\ \sqrt[4]{I}$$

It will be observed at once that this equation is of the same form, but simpler than that for pipes.

IV. With the view of investigating the action of the channel lining, MM. Darcy and Bazin had experimented on rectangular canals of equal dimensions and slopes, but with the sides and bed of different materials. The canals were formed of planks, and were revetted with

1. Plaster coating.
2. Bricks laid flat.
3. Small gravel 0·4 to 0·8 inches in diameter set in cement.
4. Large gravel 1 2 to 1·6 inches in diameter also set in cement.

Most carefully gauged and constant supplies were run through these channels and observations recorded.

M. Gauchler takes a series of these which have been condensed below into an abstract.

No	R.	I.	v.	Difference between $\sqrt{v}$ and $\alpha \sqrt[3]{R} \sqrt[4]{I}$.	α.
SERIES NO 2.—RECTANGULAR CANAL PLASTERED.					
12	0·0511 to 0 2123	0·0049	1·018 to 2·460	Never above 0·034, generally much lower.	10·
SERIES NO. 3.—RECTANGULAR CANAL IN BRICK.					
12	0·0586 to 0 2374	0 0049	0 839 to 2 047	Never above 0 045, generally far lower.	8·9
SERIES NO. 4.—RECTANGULAR CANAL REVETTED, SMALL GRAVEL.					
12	0·0761 to 0·2772	0 0049	0 658 to 1 897	Never above 0·015, generally lower.	7·5
SERIES NO 5.—RECTANGULAR CANAL REVETTED, LARGE GRAVEL.					
12	0 0888 to 0 3009	0·0049	0·547 to 1·493	Never above 0·075, generally much lower.	6·8
SERIES NO. 6.—RECTANGULAR CANAL OF PLANKS					
12	0·0733 to 0 2809	0·00208	0·635 to 1·587	Never above 0·017, average much less.	9·
SERIES NO. 7.—RECTANGULAR CANAL OF PLANKS.					
12	0·0573 to 0 2215	0·0049	0·826 to 2·179	Never above 0 031, generally much less.	9·2
SERIES NO. 8.—RECTANGULAR CANAL OF PLANKS.					
12	0·0447 to 0·1919	0·00824	1 074 to 2·612	Never above 0·029, generally much less.	9·4
SERIES NO. 9, 10 and 11.—RECTANGULAR CANAL OF PLANKS.					
17 each	0·0524 to 0 3042	0·0015 to 0·00839	0·548 to 2·664	Never above 0·035,	9·0 to 9 4

V. The agreement between the values of $\sqrt{v}$ given by experience and those involved from the formula of M. Gauchler are quite remarkable, especially when it is considered how subject to error, owing to the surface of a liquid in motion never being plane but undulating, all calculations of slope and wetted perimeter are.

The values of a decrease as the resistance afforded by the material of the channel increase, so that $\frac{1}{a}$ might be called the co-efficient of resistance.

It may be noticed that the variation in value of a for the planked channels is explained to be due to the nature of the planks in all series not being identical.

VI. M. Gauchler next investigated whether the form of the profile of the channel affected these values of a. He took up for this purpose the series 18 to 29 of MM Darcy and Bazin. It does not seem necessary to reproduce these here. It may be sufficient to say that M. Gauchler found, as indeed the investigations of M Bazin had gone to prove before, that the value of a, and therefore of the mean velocity, were independent of the form of the profile. M. Dupuit, as quoted by M. Gauchler, had concluded theoretically that the profile did affect the mean velocity, but M. Gauchler's calculations and investigations do not justify the theory. Col Anderson in the number of the Professional Papers quoted before, shows however that the circular form of section does offer, other things being the same, a sensibly smaller resistance than that offered by an angular profile.

VII. It may be useful to recapitulate the points investigated by M. Gauchler. From the first to the last, and working with recorded and carefully made experiments, he proves that the most remarkable agreement exists between experimental values of the velocity and those calculated by his formula, such an accord is not fortuitous, and would tend to convince us that the law of water-flow is given by his formula. On comparing the different values of a we see that this co-efficient varies only with the nature of lining of channel, and that it has no connection with the slope, nor with the mean radius, nor with the form of section; or if this last has an influence it is insignificant in practice.

Before passing to the study of works that are more often met with in practice than are canals of the kind that we have been studying, let us resume the result of M. Gauchler's investigations.

The formula is for French measures (mètres)

$$\sqrt{v} = a \sqrt[3]{R} \sqrt[4]{I}$$

and the following table gives the values of a for various lining materials.

Nature of channel	Values of a.
Very smooth wood or plaster, ...	10 0
Bricks set in mortar, ...	8·9
Rough gravel (fine), ...	7·5
Ditto ditto (course)	6 8
Planks, ...	9 2

To apply these values of a in practice it will be necessary to use them only where the channel is free from weed or silt. The presence of these very considerably affects the value of the co-efficient.

IX. Up to the present, the investigations have only treated of slopes greater than 0·0007 in unity. In extending his investigations M. Gauchler found that the formula did not apply to slopes less than this. He was therefore induced to modify it ultimately to

$$\sqrt[4]{v} = \beta \sqrt[3]{R} \sqrt[4]{I.}$$

He applied both formulæ to many water-courses, such as the "Rigole de Chazilly," the "Rigole de Groisbois," &c., under various conditions of slope and nature of lining, and he found that when the inclination was less than 0 0007 in unity, the formula containing the fourth root of v gave almost invariably in a vast number of trials the better results. He admits that the limit of the application of either formula may under certain conditions not be 0 0007 slope, and that this turning point may have to be modified at some future day, but it is a point, as he says, that "the future will have to resolve."

X. The various series to which he applied this latest formula are not abstracted here; it is sufficient to say that the formula was found to apply to new experiments as well as to the results of older experiments.

XI. In the application of the formula to experiments conducted by various other Engineers, M. Gauchler rejected the experiments of Funck Donati, and those of the Roman Ponts et Chaussées, as all these experimenters had not a sufficiently accurately gauged mean velocity. He found however that the experiments of Dubuat, Woltmann, Poirée,

Emmery, and Lévéillé were fairly accurate, though not quite up to the standard of those of Darcy and Bazin The experiments of Dubuat on the *Canal de Jard*, those of Poirée on the Seine at the bridge of Jena, those of Emmery on the Seine at Poissy, and those of Lévéillé on the Sâone at Raccounay, were applied to the formula applicable to slopes less than 0·0007, and were found to agree very fairly. It should be noticed that only in the last two series of the above-mentioned experiments was the mean velocity directly deduced from observation; this mean velocity was obtained in these cases by observing velocity at various vertical sections of the river profile. This though not a perfectly accurate way of obtaining the mean velocity, is the most accurate way of obtaining it for large rivers. Care was taken to register the fluctuation in rise and fall of the river, and it was found that where the observed mean velocity differed in any unusual degree from that calculated by the formula, the fluctuation in the level of the water surface had been considerable.

XII. M. Gauchler concludes his article with some interesting remarks, which are translated at length. He says:—" It only remains for us to try and explain the singular variation in the laws of water movement that we have discovered. Why does one formula represent the movement up to a certain point and another the law of motion beyond this point? Does water move in two ways? Experience seems to say so. One point particularly strikes us after considering the experiments of MM. Darcy and Bazin, and this is the permanence of rapid slopes irrespective of changes in the mean radius. The superficial slope of water seems determined by that of the bed; it is the same as the bed slope, and continues invariable whatever the thickness of the cushion of water. As the velocities on any vertical line are distributed in various ways, it is conceived that the molecule animated by the greatest velocity passes that below it which is subject to a less velocity and obeying the law of gravity falls in front of, or as it were, rolls over the latter. But as this phenomenon is produced in all molecules of superior velocity, the molecule of maximum velocity ultimately comes into contact with the bottom following some curve which cannot be determined in the present state of science. It follows, therefore, that the movement consists of a rolling of the molecules so that they all successively touch the bottom whence by their elasticity they rebound to the surface. In canals of slight slope we see on the contrary that inclinations vary independently of the slope of the

bed and with the mean radius. The molecules seem to move by virtue of the pressure of those above them, which pressure in each profile is slightly greater than the reaction of the molecule below. In this way the water moves in strata of equal velocity, and slides or rolls horizontally and not in a curve line. Experience seems to confirm these hypotheses. Every one has observed that bodies that float when immersed in a rapid current alternately appear at the surface, and disappear towards the bottom, while in rivers of low velocity, they appear to move equally and steadily on the surface. In the first case the velocity is proportional to the square root of the slope, in the second to the slope itself; and as these slopes are always inferior to unity, it follows that the movement of rolling is more rapid than that of sliding. It follows from this that at the point where river floods pass from the first to the second movement there is great agitation of water which is liable to cause an inundation at this point. Applying this observation to the Rhine, we find that the slope of 0·0007 is found near Rhinan, a place celebrated in the records of Rhine inundations for its misfortunes."

It is a matter for regret that MM. Darcy and Bazin did not also make experiments on canals of low slope. They had no reason to suppose that the law of water-flow varied as M. Gauchler now appears to prove is the case. Such experiments as M. Gauchler made with the view of verifying his second formula were on small water-courses of the Rhône canal, which naturally did not give such satisfactory results as canals specially designed for experiments would have given. M. Gauchler hopes that experiments equally exact as those of MM. Darcy and Bazin may be carried out in order that his second formula, which is the more important of the two, may be verified. In conclusion, let us resume the results of M. Gauchler's investigations.

The two formulæ to be used for canals and rivers are in French mètres.

1. When the slope is greater than 0·0007 in unity.

$$\sqrt{v} = \alpha \sqrt[3]{R} \sqrt[4]{I}.$$

2. When the slope is less than 0·0007 in unity.

$$\sqrt[4]{v} = \beta \sqrt[3]{R} \sqrt[4]{I}.$$

These formulæ are only particular cases of the general equation for pipes.

$$\sqrt{v} + \frac{D}{4} \sqrt[4]{v} = \alpha \sqrt[3]{D} \sqrt{I}$$

The co-efficients affecting the second members of these equations vary

with the nature of lining of channel, but are independent of all other conditions of flow.

The table below shows the values of the co-efficients to be employed in each formula for canals and rivers :—

Nature of channel.	α.	β.
Masonry (cut stone and mortar), ..	From 8 5 to 10·0	From 8 5 to 9 0
Good masonry, ...	„ 7 6 „ 8 5	„ 8 0 „ 8·5
Masonry sides ; earth bottom, ...	„ 6·8 „ 7·6	„ 7 7 „ 8·0
Small water-courses in earth free of weeds,	„ 5·7 „ 6 7	„ 7·0 „ 7·7
Ditto do. grass on slopes,	„ 5·0 „ 5 7	„ 6·6 „ 7·0
Rivers, ...	Nil.	„ 6 3 „ 7 0

For English measures (feet) the formulæ will be

$$(1) \quad \sqrt{v} = 1{\cdot}219\, \alpha \sqrt[3]{R} \sqrt[4]{I}$$

$$(2) \quad \sqrt[4]{v} = \frac{B}{1{\cdot}104} \sqrt[3]{R} \sqrt[4]{I}$$

W. G. R.

Since writing the above a note on employment of the formulæ of M. Gauchler by M. Stapfer, Engineer of the "Ponts et Chausseés," published in the volume for July 1869, has appeared

M. Stapfer carried out some experiments on open canals lined with masonry, taking off from the Marne. In one case the canal was 8 mètres or 26·25 feet wide at the bottom, with a depth at low water of 1·75 mètres or 5·74 feet, and at high water of 4·25 mètres or 13·94 feet. This canal was navigable and also worked a water wheel. The maximum surface velocity allowed by the grant or "concession" was 0·55 mètres or 1·8 feet per second. The corresponding mean velocities to give the surface velocity and values of I deduced from De Prony's formulæ were, therefore,

	mètres.	
In low supply, mean velocity, ...	0·434,	and I-0·00006444
In high „ „	0·434,	and I-0·00003807

If in M. Gauchler's second formula these values of I be substituted,

and β be taken $\frac{8 + 8{\cdot}5}{2} = 8{\cdot}25$, the mean velocities given would be

In low supply, ...	0·388
In high supply, ...	0·463

or, conversely, if M. de Prony's value of mean velocity or 0·434 mètres be used in the formulæ of M. Gauchler, we get the values of β to be

$$\text{In low supply } \beta = \frac{\sqrt{v}}{\sqrt[3]{R}\,\sqrt[4]{I}} = 8{\cdot}48.$$

$$\text{In high supply } \beta = \frac{\sqrt{v}}{\sqrt[3]{R}\,\sqrt[4]{I}} = 8{\cdot}12.$$

The mean of these values of β is 8·30.

M. Gauchler's value of β for good masonry is 8 to 8·5, which gives a mean of 8·25. The results deduced from the formulæ of de Prony it will be seen, therefore, are very nearly the same as those deduced from the formulæ of M. Gauchler in this particular case.

M. Stapfer considers that either formula may be used indifferently for open canals revetted with good masonry. He remarks, however, that to employ M. Gauchler's formula, the value of I must be exactly known, which in practice, owing to various causes, is seldom the case. He prefers therefore in such cases (where the slope is inferior to 0·00007)* to employ De Prony's formula for mean velocity derived from surface velocity to finding the velocity from M. Gauchler's formula No. 2. He agrees with M. Baumgarten, having himself verified this gentleman's deductions, in further reducing De Prony's mean velocity when the surface velocity is over 1·30 mètres (or 4·264) by again multiplying by 0·80. De Prony based his formula on only 15 experiments, in none of which was the surface velocity greater than 1·299 mètres, whereas Baumgarten based his modification of the value of mean velocity on 22 experiments, all of which the surface velocity exceeded 1·40 mètres (or 4·592 feet)

But extending his calculations to another case (width of bed 9 mètres (29·52 feet), depth of water 3·5 mètres (11·48 feet), channel masonry with vertical sides, discharge 45 cubic mètres per second (1589·26 cubic

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feet per second), M. Stapfer found the value of I by De Prony's formula to be 0·0003975. This brought this case under the conditions of M Gauchler's first formula. The value of a was taken $\frac{7·6 + 8·5}{2} = 8·05$, and I deduced by M. Gauchler's formula was 0·0001638, or less than half that deduced by De Prony's formula.

This difference can only be explained by the fact that M de Prony's formula is a more general one than that of M. Gauchler, based as it is on experiments conducted in channels with various linings, whereas the formula of M. Gauchler are more definite, and the co-efficients determined by a large number of experiments for each different lining. For example if the same discharge of 45 cubic mètres had been given by a river channel, and mean dimensions of which were the same as this masonry channel, we should have had by M. Gauchler's second formulæ β being $\frac{6·3 + 7}{2} = 6·65$

$$I = \frac{v}{\beta^4 R^{\frac{4}{3}}} = \frac{1·43}{(6·65)^4 (1·968)^{\frac{4}{3}}} = 0·0002965$$

or taking β, 6·3

$$I = 0·0003372$$

which is very nearly De Prony's 0·0003975. M. Stapfer concludes from his investigations that either the formula of De Prony or Gauchler can be used when two of the three terms v, R and I are given, when the surface velocity does not exceed a certain limit. This limit he does not state very exactly, " 0·55 mètres par exemple " are his words. He concludes his article in the following words:

" To resume, I am inclined to conclude from this comparison between the formula of De Prony and Gauchler.

" 1st. That the later formulæ as based on a larger number of experiments are more accurate for determining either the mean velocity, or the slope, when the slope or mean velocity are accurately given.

" 2nd. That the formulæ of De Prony are to be preferred when either of these terms cannot be determined with exactitude, and when for instance the velocity can only be calculated by the use of floats.

" 3rd. That till formulæ more exact and as easy to use in practice as those of De Prony are discovered, it is sufficient to deduce the mean velocity from the formula of De Prony modifying it by the rule of Baumgarten when the surface velocity exceeds 1·40 mètres (4·6 feet).

"*4th.* That in canals lined with good masonry when the surface velocity does not exceed 0 55 mètres, the formulæ of De Prony and Gauchler give almost identical results.

"*5th.* That for rivers the old formulæ of De Prony, and the new one of Gauchler, furnish results that differ but slightly even when the surface velocity exceeds 1·40 mètres, and that the former being more easy in application should rather be used."

M. Stapfer is evidently inclined to sustain the old formulæ of De Prony against those of M. Gauchler or M. Bazin. But the formulæ of these last based on very careful and numerous experiments are to be preferred. These formulæ are given below as adapted to English feet; R, I, v being the same in both, that is to say

v = mean velocity in feet.
R = mean radius in feet.
I = fall in unity.

M. Gauchler :—

(1). $\sqrt{v} = \alpha \times 1{\cdot}219 \sqrt[3]{R} \sqrt[4]{I}$, slope being greater than 0·0007.

(2). $\sqrt[4]{v} = \frac{\beta}{1{\cdot}104} \sqrt[3]{R} \sqrt[4]{I}$ slope being less than 0·0007.

M. Bazin :—

1st class, bed and sides planed planks, plaster, &c.,

$$\frac{RI}{v^2} = 0{\cdot}0000045 \times \left(10{\cdot}16 + \frac{1}{R}\right).$$

2nd class, bed and sides cut stone, brickwork, &c.,

$$\frac{RI}{v^2} = 0{\cdot}000013 \times \left(4{\cdot}354 + \frac{1}{R}\right).$$

3rd class, bed and sides slightly uneven (rubble)

$$\frac{RI}{v^2} = 0{\cdot}00006 \times \left(1{\cdot}219 + \frac{1}{R}\right).$$

4th class, bed and sides uneven (earth)

$$\frac{RI}{v^2} = 0{\cdot}00035 \times \left(0{\cdot}2438 + \frac{1}{R}\right).$$

W. G. R.

[NOTE BY THE EDITOR.]

In connection with the questions discussed in the foregoing paper, attention may be directed to the opinions advanced and results arrived at by the Rev. Canon Moseley, M.A., D.C.L., F.R.S., in a paper "On the Uniform Flow of a Liquid," read on the 2nd February, 1871, before the Royal Society, of which the following is a brief resumeé:—

"The resistance of every molecule of a liquid at rest which a solid (by moving through it) disturbs, contributes its share to the resistance which the solid experiences; so that the inertia of each molecule so disturbed and its shear must be taken into account in the aggregate which represents the resistance the liquid offers to the motion of the solid. The motions communicated to the molecules of a liquid by a solid passing through it, and the resistances opposed to them, however, are so various, and so difficult to be represented mathematically, that in the present state of our knowledge of hydrodynamics the problem of the resistance of a liquid at rest to a solid in motion is perhaps to be considered insoluble. As it regards the opposite problem of the resistance of a solid at rest to a liquid in motion (as in the case of a liquid conveyed through a pipe), there are in like manner to be taken into account the disturbances created by that resistance in what would otherwise have been the motion of each individual molecule of the liquid so disturbed.

This problem, however, is by no means so difficult as the other. There is, indeed, a case in which it admits of solution. It is that of a liquid flowing from a reservoir, in which its surface is kept always at the same level, through a circular pipe which is perfectly straight, and of the same diameter throughout, and of a uniform smoothness or roughness of internal surface, and always full of the liquid. The liquid would obviously in such a pipe arrange itself in infinitely thin cylindrical films coaxial with the pipe, all the molecules in the same film moving with the same velocity, but the molecules of different films with velocities varying from the axis of the pipe to its internal surface. The direction of the motions of the molecules of such a liquid being known, and all in the same film moving with the same velocity, which velocity is a function of the radius of the film, and the law of the resistance of each film to the slipping over it of the contiguous film being assumed to be known, as also the head of water, it is possible to express mathematically

(1st) the work done per unit of time by the force which gives motion to the liquid and

(2nd) the work per unit of time of the several resistances to which the liquid in moving through the pipe is subjected, and

(3rd) the work accumulated per unit of time in the liquid which escapes—and thus to constitute an equation in which the dependent variables are the radius of any given film, and the velocity of that film. This equation being differentiated and the variables separated, and the resulting differential equation being integrated, there is obtained the formula

$$v = v_0 \varepsilon^{-\frac{250\, r}{l}},$$

where v is the velocity of the film whose radius is r, and v_0 that of the central filament, and l the length of the pipe—the unit of length being one mètre, and of time one second.

The method by which the author has arrived at this formula is substantially the same as that which he before used in a paper read before the Society on the "Mechanical Impossibility of the Descent of Glaciers by their weight only," and which he believes to be a method new to mechanical science. It was indeed to verify it in its application to liquids that he undertook the investigations which he now submits to the Society, which, however, he has pursued beyond their original object.

The recent experiments of MM. Darcy and Bazin* have supplied him with the means of this verification. These experiments, made with admirable skill and precision, on pipes upwards of 100 mètres in length, and varying in diameter from $0^{m}\cdot0122$ to $0^{m}\cdot5$, under heads of water varying in height from $0^{m}\cdot027$ to $30^{m}\cdot714$, include (together with numerous experiments on the quantity of water which flows per second from such pipes under different conditions) experiments on the velocities of the films of water at different distances from the axes of the pipes, made by means of an improved form and adaptation of the well-known tube of Pitot. These last mentioned experiments afford the means of verifying the above-mentioned formulæ. With a view to this verification, the author has compared the formula with sixty of the experiments of M. Darcy, and stated the results in the first two Tables of his paper.

The discharge per 1″ from a pipe of a given radius may be calculated from the above formula in terms of the velocity of the central filament. This calculation the author has made, and compared it with the results of eleven of M. Darcy's experiments.

Where in the formula which thus represents the discharge from a pipe of given radius, in terms of the velocity of the central filament, the radius is made infinite, an expression is obtained for the volume of liquid of a cylindrical form, but of infinite dimensions (laterally), which would be put in motion by a *single filament* of liquid which traversed its axis, and, conversely, it gives the volume of such a liquid in motion which would be held back by a filament of liquid kept at rest along its axis. Thus it explains the well-known retarding effect of filaments of grass and roots in retarding the velocities of streams.

It is the relation of the velocity of any film to that of the central filament which the author establishes in the above formula. To the complete solution of the problem it is necessary that he should further determine the actual velocity v_0 of the central filament. This is the object of the second part of his paper. This velocity being known, the actual discharge per 1″ is known. The following is the formula finally arrived at —

$$Q = C\left[\varepsilon^{-\frac{250\,R}{l}} - \frac{250\,R}{l} - 1\right]R^{\frac{1}{3}}\,h^{\frac{1}{2}}\,l^{\frac{7}{3}}$$

where

Q = discharge per 1″ in cubic mètres.
R = radius of pipe in mètres.
l = length of ditto.
h = head of water.
C = a constant dependent on the state of the internal surface of the pipe.

* Recherches Expérimentales relatives au mouvement de l'Eau dans les Tuyaux, par H. Darcy: Paris, 1857. Recherches Hydrauliques, par MM. Darcy et Bazin. Paris, 1865.

The values of this constant C, as deduced from the experiments of M. Darcy are given,

1st, for new cast-iron pipes ,

2nd, for the same covered with deposit ,

3rd, for the above *cleaned* ;

4th, for iron pipes coated internally with bitumen ;

5th, for new leaden pipes ,

6th, for glass pipes.

The author compares this formula with sixty-two of M. Darcy's experiments, and records the result of this comparison in the last three Tables of his paper.

The paper concludes with an investigation of the rise in the temperature of a liquid flowing through a pipe caused by the resistance which its coaxial films oppose to their motions on one another (or, as it is termed, their *frictions* on one another) and on the internal surface of the pipe. The pipe is in this investigation supposed to be of a perfectly non conducting substance."

A. M. L.

No. XXV.

VEHAR LAKE DAMS.

[*Vide* Plates Nos. XVII., and XVIII.]

Reports to the Municipality of the City of Bombay. BY CAPTAIN HECTOR TULLOCH, R.E., *Executive Engineer.*

Bombay, 5th December, 1870

Report, No. I.—Although you are perfectly aware of the state of No. 2 Dam of the Vehar Lake, from your recent inspection of the work, I think it will be well for me to place on record the facts in connection with the leak lately discovered.

On Saturday the 26th November in the evening, it was for the first time ascertained for a fact that water was escaping through the dam. On Sunday morning I drove out and examined the position of the leak carefully, and came to the conclusion that the level of the point where the water issued was about 10 or 12 feet below the present surface of the lake, and probably not more than 50 feet from the eastern end of the dam.

The clearance of the brushwood and reeds at the bottom of the embankment has shown that the leak is not confined to the spot where it was first discovered, but that water is escaping in ten or twelve different places, the total discharge being about equivalent to a stream two feet wide and one inch deep.

Not a moment was lost in setting about the repair of the dam, and already the measures taken have produced a marked effect, and I have no doubt whatever that the leak will be soon effectually stopped. There is nothing to suggest any immediate danger. It is impossible to estimate

accurately what the repairs may cost, but, roughly speaking, Rs. 30,000 should suffice.

10th December, 1870

Report, No. 2 —I have the honor to report to you that I have this day completed my inspection of Dam No. 3 of the Vehar Lake. I had previously informed you that this dam was leaking, but I was not prepared for the state of things which has now come to my notice. I had a breadth of from 6 to 10 feet of the pitching on the exterior slope removed so as to expose the earthern face of the embankment, and I have discovered a series of leaks occurring here and there, but extending over a length of at least a hundred yards. The character of these leaks I consider much more serious than that of those found in No. 2 Dam. There cannot be a vestige of doubt in the case of No. 3 Dam as to where the water is escaping from. Everywhere it is escaping right through the embankment. Now although here is nothing at all alarming about the leaks as they are at present, I am of opinion that immediate steps should be taken to stop them, as at any moment they may increase, and lead to the sudden destruction of the dam.

You are aware of the plan which I am adopting at No 2 Dam. A new puddle wall seven feet thick is being built behind the old one, or rather behind the place where the old one ought to be, for at present no trace of any puddle wall at all has been found. The wall is being built in short lengths of ten feet each, and the trench dug is strongly close-timbered throughout. I feet confident that the measures which I have adopted will prove successful, although I cannot, considering how very badly the embankment was originally built, guarantee that at some future period a leak may not spring again.

Regarding No. 3 Dam, however, it is necessary I should inform you that the works required to stop the leaks in it will not only be attended with very considerable expense, but they will require the very greatest care and caution on my part to carry out to success. I propose the same plan as that adopted for No. 2 Dam, but the appliances to carry it out will be far more extensive. The wall will be built in short lengths, but in this instance, not by close-timbering, but by close piling. Timbering similar to that used at No. 2 Dam would be attended with danger under the great pressure of water that we should have to contend against. Close

piling will be very expensive, but it will be comparatively safe; I say comparatively, because I cannot disguise from you that work of this nature can never be entirely free from some danger.

You will see in the accompanying Plan, Plate XVII, which I have roughly drawn out myself, the position of the puddle wall proposed to be built. I have also drawn an alternative scheme, but I must say plainly I am strongly in favor of the system of close piling. The second scheme would not be nearly so expensive, but it would not in my opinion be nearly so effective.

Where the interests, the safety, of the lives and property of nearly a million people are concerned, I think, however assured I may be of the success of the measures proposed by me, I should be doing wrong not to advise that a consultation of the best engineering talent in Bombay be held on the means to be adopted for rendering No 3 Dam secure. Indeed, if I may be permitted to mention the names of the gentlemen who I think should be asked to the consultation, I would mention Colonel Kennedy, Colonel Trevor, Mr. Ormiston, and Mr LeMesurier.

My motives in thus candidly advising you to call in others to consult with me could never, I am aware, be misconstrued by yourself, nor, I am sure, will they be by the Bench of Justices when they learn that specific plans having been submitted by me for repairing the dam, I have thus exposed myself to the criticism of my brother Engineers.

Minutes on Capt H. Tulloch's Proposals.

I. By Thomas Ormiston, Esq., Member Institute C.E.

13th December, 1870.

1. Captain Tulloch stated that no gauging had been taken of the leaks, but he thought they were increasing.

2. He was asked to have them measured daily and registered.

3. The long grass had been cut away from the foot of the outer slope and thus showed the leakage,

4. It does not appear to be a single leak but a general soakage.

5. I don't think the dam shows any immediate symptom of failure, nor do I think it is worse than it has been for some years.

6. I do consider, however, that if any repair or addition can be made which will substantially increase the strength of the dam, it should be done.

7. Captain Tulloch suggested a puddle wall to the outside slope, which he consi-

dered might be done in either of two ways, as shown in the accompanying plan, which is the one produced by Captain Tulloch at the leak.

8. I do not agree that the new puddle wall should be put in as shown; both ways show it cracked, and it would probably settle and crack at the angles.

9. The puddle wall should be vertical.

10. The effect of inserting a water-tight puddle wall outside of the supposed present one will be to stop the present leakage, and thus the whole bank to the water side of the new puddle wall will become fully charged with water, and be little better than sludge.

11. Wherever the new puddle wall be placed, it must have as good a bank of earth outside of it as the present supposed puddle wall has.

12. The exact position for the new puddle wall can only be ascertained by trial estimates. It may be where Captain Tulloch has placed it, or it may be either within or without it.

13. Piling should not be made use of. The vibration would be sure to bring in the dam if it is shaky.

14. The new puddle trench and outer slope should be done in sections, *i. e.*, not all at once.

II. BY COL. M. K. KENNEDY, R.E.

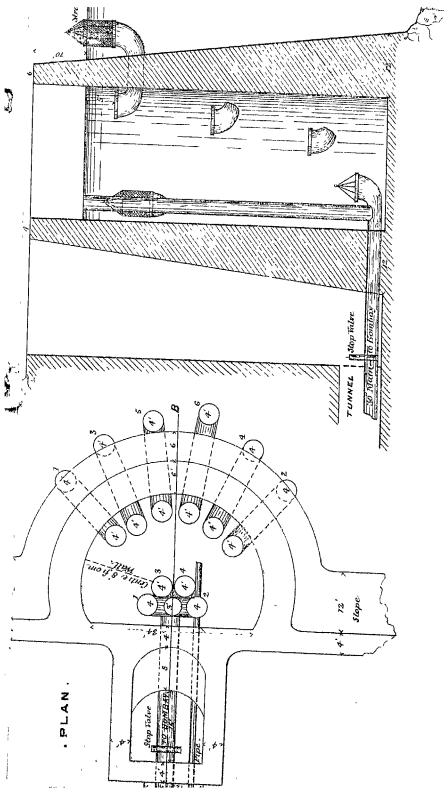
17th December, 1870.

I agree with Mr. Ormiston in thinking that the dam is in no immediate danger; it is not probably in any worse condition than it has been in for years. There is a slight weeping through parts of it, which was not plainly observable till the pitching was removed. It is tighter than 9 out of 10 of the irrigational bunds to be found throughout the country that have been in existence for generations, in Dharwar for instance it would be considered a remarkably good bund. If revenue depended on it, I should say that nothing was necessary, but it is a more serious matter when the health of a large City and the lives of thousands may be said to depend on the Lake; under such circumstances nothing should be left to chance. My only doubt is whether anything that can be done will mend matters much. It is worth, however, the expenditure of a reasonable sum to try and endeavour to allay the uneasy feeling which exists in regard to the dams, more especially among persons not competent to form a judgment. The only thing to be done is to erect a puddle wall, and I concur with Mr Ormiston in thinking that this should be vertical. I would place it as near the back of the existing puddle wall as can safely be done. After this has been done, however, we must be prepared to find matters very little if at all better than they are now. The flow of water below the bund should be carefully and continuously gauged.

III. BY COL. J. S. TREVOR, R.E.

18th December, 1870.

I agree with Mr. Ormiston and Colonel Kennedy in considering the dam is in no immediate danger. But as long as there is extensive leakage, as at present, apprehensions will be entertained for its safety. The consequences of failure of the dam are so serious, that these apprehensions, by whomsoever brought forward, will com-

. PLAN .
Stop Valve
TO BOMBAY
Pipe
Centre 8' from wall.
B
Slope
TUNNEL
Stop Valve
30" Main to Bombay

mand attention, and attempts will from time to time be made as heretofore for stopping the leaks. These attempts would in the end cost far more than a systematic plan for placing the dam beyond all reach of danger. I think a vertical puddle wall close to the work, and placed some distance on the outer side from the existing puddle wall, would have this effect, and if its erection was watched by competent persons on whom the public would place faith, and register kept of what was done, so that hereafter the character of the work could not be recklessly called into question, the expenditure of some considerable sum of money would be advisable, although it cannot be said that such an outlay is emergently necessary.

IV. By H. P LeMesurier, Esq , C E.

18th December, 1870.

The probabilities are that the dam has been for some time past in the same condition as that in which it now is, and this is not a state that can be called anything but exceedingly unsatisfactory, considering the interests at stake

The dam should be put into thorough repair, and perhaps the best way of effecting this end is *to put in a vertical puddle wall at a safe distance in rear of the present* supposed puddle wall, as noted by Mr. Ormiston, backing it up with the requisite embankment to make all secure, and not placing much, if any, reliance on the earth and puddle between the face of the new puddle wall and the water

I agree with Mr Ormiston as to the inexpediency of shaking the existing bank by *any heavy pile-driving operations*.

A very complete record in brief form should be kept about the future operation and the existence of this record, and its whereabouts, should be widely made known so that there may be no question hereafter as to the existence or otherwise of puddle wall No 2.

Very great care should be bestowed upon the construction of the new work, and its stability should be ensured by every possible expedient, and the closest supervision by trustworthy men, insufficient numbers to provide for regular reliefs, if the work is carried on during long hours each day

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Bombay, 25th July, 1871.

Report, No. 3.—On the afternoon of the 26th November 1870, Mr. Pyne, the Superintendent of the Vehar Water Works, reported to me that he had discovered what appeared to him to be a very serious leak on the side of No. 2 Dam, and that, as he had never observed this leak before in his examination of the dam, he was of opinion that it must have sprung recently.

On receipt of this information, I lost no time in making a personal inspection of the dam in question. I visited the Lake the next morning, and after careful examination satisfied myself that the reported leak was of such a nature as to demand immediate attention. I ascertained that the points of the egress of the water through the exterior face of the dam

were from ten to twelve feet below the surface of the lake at the time. In other words, the surface of the lake being then five feet below the waste weir, the leaks were taking place from fifteen to seventeen feet below that level.

On further examination I noticed that a large quantity of brushwood and reeds had accumulated at the foot of the dam, and that they had that verdant appearance which is only found in vegetation growing close to water. I accordingly had the weeds removed, when my worst anticipations were, I regret to say, realized Numerous leaks existed, and there was a large escape of water. A gauge was immediately set up, which showed that the quantity of water running through the dam was equivalent to a stream one foot wide and $1\frac{1}{4}$ inches deep, flowing with a velocity due to a fall of one foot in sixteen.

Before deciding what was to be done, I searched the records of our office in order to find the original plans and sections of the dam. These showed, to my surprise, a vertical puddle wall, ten feet wide at the top, and twenty feet wide at bottom, running along the entire length of the work. Under these circumstances the only conclusion I could come to was either that the puddle wall must have been badly built, or that it was a myth. Inquiries made by me in Bombay convinced me that the dam had originally been built without a puddle wall, and the facts elicited by our future operations rendered this clear beyond the shadow of a doubt. Had there been a puddle wall we must have come on it, but the dam was perfectly innocent of this safeguard. Neither at the top nor at the bottom did we find any puddle wall. So shamefully was this work constructed, that in parts where puddle should have been found, we found instead layers of, what might not at all inappropriately be termed, road metal. Only to give an idea of the bad nature of the soil in the dam, and its utter inadaptibility to the purpose for which it was used, I will state what actually took place under my own eyes.

A trench was dug in the dam *sixty feet from the margin of the water in the lake.* The bottom of this trench was only one foot below the level of the water, and it was actually flooded,—that is to say, the soil was so unretentive that a pressure of only 12 inches of water forced the water through a thickness of sixty feet of soil.

There has never been any doubt in my mind as to the mode of repairing a leaky dam, but I have never disguised from myself the dangerous

nature of such work. The great risk arises from our never being perfectly aware of the state of the interior of the dam, and of our being compelled to work as it were in the dark The inside of the dam may be hard and firm, or it may be like a quicksand No water may escape to render the soil difficult to work in, or floods of water may be expected. But whatever may be the state of the dam the water can only be retained in a reservoir by means of a puddle wall. The question therefore at once resolves itself into this—Where should the puddle wall be placed in a leaky dam, so that the least risk of danger shall be run? I am most emphatically of opinion that it should be put into the dam by cutting into it somewhere on its *exterior* face I believe a puddle wall dropped into the dam on the interior face *might be* more effectual (even this is questionable), but the danger of carrying this wall right down into the original firm ground (a *sine quâ non* in any case), with a great head of water pressing on the works should make any one desist from the attempt.

The plan of operations which I adopted at No. 2 Dam was to drop a vertical puddle wall, eight feet thick, just behind where the original puddle wall should have been, and down into the original soil, and in order to run as little risk as possible I determined to do this work by sinking shafts in as short lengths as men could work in conveniently. It was a source of great gratification to me subsequently to find that the precautions I had taken were justified by the nature of the work. In some of the shafts the soil proved most troublesome, being almost of the nature of quicksand, and to add to our difficulties water came pouring in such large quantities, that pumping had to be continued night and day to keep the foundation dry. In every case the shafts were sunk down 4 or 5 feet into the original ground.

The works at No. 2 Dam are completed, and the best proof of their efficiency is afforded by the almost total disappearance of the leaks. It is hopeless to expect to stop them entirely. The reason is that the water which is now running is not escaping from the dam, but through the hills on the sides, and partly from under the dam at a great depth below the natural surface of the soil. In order to show that this is the case, and not an assumption on my part, I may mention that I had a series of shafts sunk in the valley about a hundred feet from the foot of the dam. These shafts were sunk in some cases to 20 feet below the surface, and even at this depth the water from the direction of the lake came pouring

in such quantities, that the men at work could not keep the shafts dry. The truth is that the subsoil on the site on which the dam is erected is composed in great part of trap rock in a disintegrated state. What ought to have been done originally was to remove this soil, until firm rock was reached, and on this foundation the dam should have been built. Nothing can be done now to rectify this error.

While the work was in progress at No. 2 Dam, it occurred to me that a more careful examination of Dams Nos 1 and 3 should also be made. Mr. Pyne had not reported any leaks in them, but I thought it better to satisfy myself on the subject

On examining No. 3 Dam, I found at a certain level below the water that the short grass growing on the exterior face was suspiciously green in numerous places. The removal of a few of the pitching stones showed clearly that the dam was leaking, but in order to arrive at a more correct estimate of the extent of the leaks, I had a strip of the pitching (10 feet wide) removed along the entire length. I was certainly not prepared for the state of things which this simple measure revealed. The dam was found to be leaking along a length of about a hundred yards, and the water was escaping unmistakeably through the body of the work. There could be no gainsaying this, as the leaks were as much as a hundred yards from the hills on sides, and at a level of about 25 feet from the foot of the dam.

It having been repaired in 1867 by my predecessor, Mr. Aitken, I had always understood that No. 3 Dam was in a sound state. Until the discovery of the leaks indeed it had never occurred to me to examine the plans explanatory of the work executed in that year. I now examined both these plans and the original plans on which the dam was, or was supposed to be constructed. The latter showed a vertical puddle wall in the middle of the dam, but inquiries made in Bombay convinced me again that this puddle wall was a work of the imagination, and had no actual existence. Here then again I was called upon to deal with a case similar to that of No. 2 Dam.

Mr. Aitken's plans showed that he had dropped a puddle wall through the *interior* face of the dam. This work however had not been carried into the original soil, but only to a depth of about thirteen feet below the surface of the water at the time when the work was under execution.* It

* *Vide* Plate, XVII., *work done in 1868.*

was manifest therefore that the water escaping from the lake, supposing this puddle wall was impervious, was escaping from under the wall. I was more than ever convinced therefore that the plan I had adopted at No. 2 Dam was the only effectual way to grapple with the difficulty. Only by working on the *exterior* face of the dam could I hope with safety to carry my puddle wall into the natural soil, which I consider, as I have said before, a *sine quâ non* towards the permanent prevention of dangerous leaks.

Although the work at No 2 Dam was progressing most favorably at this time, and although the effect of it was already visible in the reduction of some of the leaks, and I had no reason to anticipate but perfect success, I did not hesitate to point out to you the serious nature of the difficulties before me with regard to No 3 Dam. Here it was certain that we should have a greater pressure of water to contend with, and nearly certain, from the extent of the leaks on the face of the dam, that the quantity of water in the shafts would be a serious hindrance to our work. The danger was considerably increased from the great length of the dam. In a matter however which involved the well-being, and indeed the safety of the lives and property, of nearly a million people, I thought, however confident I might be in my own opinion, that I should be doing wrong not to obtain the opinion of others. I considered that the Bench would feel greater satisfaction if my work had the stamp of the approval of the best professional men in Bombay. I was not unwilling to have my work subjected to criticism, and indeed, for all I knew, it might have been censure. Accordingly I requested you to ask the following gentlemen—Colonel Kennedy, Colonel Trevor, Mr. Ormiston, and Mr LeMesurier—to form a Committee to advise on the matter. To this Committee on its visiting the works I submitted my proposition, with plan,* that a vertical wall should be dropped into the exterior face of the dam either just below where the original puddle wall ought to have been, or about the middle of the slope. I pointed out that it might be done in two ways;—either by sinking shafts supported in the ordinary way by sheeting and struts, or by shafts supported by a close sheeting of piles. Although I adopted the former plan in No. 2 Dam, I recommended the latter as more secure in this case, because of this extra pressure of water, and of the uncertainty as to the state of the interior of the dam. I recommended moreover that the puddle wall when brought up to the surface of the exterior slope

* *Vide* Plate XVII., Plans I. and II.

of the dam should be continued along the slope to the top, or continued in a zigzag

The Committee were of opinion that the driving in of piles might shake the dam, and they preferred the ordinary method of sinking the shafts—that in fact which was being adopted in No. 2 Dam. They moreover differed from me regarding the upper portion of the puddle wall. They were of opinion that it should be carried vertically nearly to the level of the top of the dam, and that the exterior slope of the dam should have the same inclination as it had before. On the main question they agreed with me unanimously, that the puddle wall should be dropped into the exterior face of the dam, and down into the natural soil*.

Thus then by their proceedings the Committee practically approved of the measures which were being adopted at No. 2 Dam, and, with the modification of the puddle wall being continued vertically to the level of the top of dam, they approved of the measures I proposed to adopt regarding No. 3 Dam. Setting aside my own opinion on the immaterial point on which I differed from the Committee, and on which I still differ, because it has rendered the work so much more expensive than it would have been,—the repairs have been carried out according to their recommendation.

It is necessary the Bench should know that some of the work in this dam was of a most serious nature, and had not the greatest precautions been adopted, the stability of the dam itself might have been endangered. We have been compelled to work often without stopping for days and nights together. At times the shafts have been flooded with water pouring in from the lake, and it has required the greatest energy on the part of Messrs. Glover and Co. to get the shafts dry. With fever, too, constantly breaking out among the men, the work has been carried out with an amount of perseverance which speaks highly for Messrs. Glover and Company

I may here parenthetically remark, with reference to the opinion which seems to have obtained amongst the Committee, viz., that the leaks in No. 3 Dam had probably been as bad for some years as they were when examined by themselves, that I think they are in error. On this point my predecessor, Mr. Aitken, C.E., states at page 6 of his Annual Report for the year 1867 :—

* *Vide* Annexed Minutes, pp. 261-2-3.

"Why this embankment was not made water-tight at first, I cannot pretend to give an opinion with any degree of certainty, but it is a fact that it never held water from the time the lake filled. The quantity which leaked through at first was not sufficient to cause any serious uneasiness, *but year after year the leakage increased until at last it became so serious*, that in 1865, Government appointed a Committee of Military and Civil Engineers to report as to the best remedial means to be adopted to stop the leakage. The Committee decided that the whole of the inside face of the Dam above low water level, should be coated with two or three feet of puddle."

In the next para. but one of his report Mr. Aitken also states that the gaugings showed the leakage after the monsoon of 1866 to be greater than that after the monsoon of 1865. With such evidence it cannot be stated that the danger was not increasing. Mr. Aitken not only carried out the suggestion of the Committee of 1865, but made the addition to it of a puddle trench 15 feet deep at the foot of the puddle facing.

On the completion of these works Mr Aitken stated in his report (already alluded to) that, "as the water rose after the rains set in, it was satisfactory to observe that all the old dangerous leaks were stopped, and the embankment may now be pronounced to be in a tolerably safe state." Now as I have ascertained from Mr. Pyne, who was actually engaged on this work, that at its completion nearly all the leaks had disappeared, and as I found the dam on the removal of the pitching to be leaking along nearly its entire length, I am of opinion that the leaks have not only increased, but, that they have increased to such an extent as rendered immediate action on our part imperative.

The effect of the work carried out at No. 3 Dam is plainly visible by the reduced quantity of water escaping through the work.

I was in hopes that I should complete the work this season, but I have found it impossible to do so. The difficulties have arisen from our not being able to employ more than a limited number of men. The shafts have, for safety's sake, been sunk in short lengths, and I considered it would be dangerous to the stability of the dam to open up more than three shafts at the same time. The consequence has been that we have never been able to open fresh ground until the shafts in hand have been completed. You are aware what a very threatening appearance the sky assumed in the early part of May. It seemed to be the common opinion

in Bombay that the monsoon was about to set in a month before the usual time. At Vehar, on the site of our works, we had constant rain in the mornings. Numbers of the coolies moreover left the works and would not return, being convinced that the monsoon had set in. I do not disguise that this state of things caused me an amount of anxiety which I have seldom experienced in my life. Many of my brother Engineers will understand what this means I had looked forward to working with perfect safety certainly up to the end of May, possibly up to the 10th of June, whereas the monsoon was actually threatening us in the beginning of May. It would have been little short of madness to run any risk under these circumstances, and the continuation of rain morning after morning at Vehar made me decide to close our works for the season, and render all safe. Only three more shafts had to be sunk and filled up. Two were down halfway, and it did seem a thousand pities not to defy the weather, and carry on the work for another fortnight, which was all the time required. But I was determined that I should not be tempted out of the direct path of my duty, which I considered was at any cost to have the works safe against the setting in of the monsoon. My determination once taken has been rigidly adhered to, and No. 3 Dam remains therefore not quite completed, but still safe for the season, and the three shafts are left to be sunk next season. The form of the dam as it is at this present moment is represented in the last cross section on Plate XVII

As the repairs to the Vehar Dams have attracted a great deal of attention both among the Justices and in the town, and as it would have been impossible for me to convey to the mind by mere description the nature of the work and the means adopted to carry it out, I have had two photographs* taken of No. 3 Dam. The first shows the entire dam at one view with the whole of the works in progress. The other shows a portion of the dam with the men at work and the method of sinking the shafts.

The work was commenced by Messrs. Glover & Co., on a Schedule of Rates, but, after we had made sufficient progress with the work to judge of its nature, and when I found that the work was of so uncertain a character, and liable to lead to endless disputes, I considered it would be fairer to all parties, and more satisfactory to ourselves, if they carried out the work as if it were departmental, and received a profit of 15 per cent. on the outlay to cover supervision and use of all plant. As you approved

* Not reproduced in this publication.

of this suggestion, both No 2 and No. 3 Dams have been completed on this understanding. The work has been repeatedly examined by both myself and the Deputy Executive Engineer. The daily Nominal Rolls of the firm have been checked by the superintendents placed in charge, and the weekly rolls have been sent to the office as the work progressed. The total cost of the works is Rs. 1,09,758.* The cost of the works executed in 1868 was Rs. 46,000. The last section on Plate XVII., shows the character and extent of the works carried out in 1868, and recently.

Nor has the sanitary aspect of the question been overlooked or neglected. The neighbourhood of the Vehar Lake is well known to be very feverish. Anticipating therefore that the men employed at the dam would be liable to attacks of this nature, the services of a Government Apothecary were obtained. Every measure moreover was adopted to prevent the pollution either of the lake or even of the ground near it. Temporary latrines were erected, and the night-soil was daily removed to a distance.

It is necessary now that I should say a few words regarding No. 1 Dam. I examined it on the 10th December, and found it in good order. There were a few leaks, but these were not through the dam, but through the natural soil under the dam. The leaks in fact are precisely of the same nature as those which remain in No. 2 Dam, now even that we know for a fact that a puddle wall exists and has been carried many feet into the natural soil and from hill to hill. No. 1 Dam seems at present in as sound a state as work constructed with the indifferent material to be obtained at Vehar can be expected to be But how long it may remain so, it is impossible to say. A time must come when the 41-inch iron main running through it must be worn away. No arrangements were made in the construction of the Dam to enable the Engineer to put down another main when this one became useless. Should a leak ever occur in this main under No. 1 Dam, it will be a most serious matter for the town, and the very worst consequences may be expected.

The pipe lies about seventy feet from the top of the dam, and there is a pressure of from 63 to 50 feet of water on it, dependent on the lake being full or otherwise. Supposing there is a burst in the main (and this supposition is no extraordinary one), water will issue from the pipe with a pressure of say 25 lbs. on the square inch. What the effect of a stream

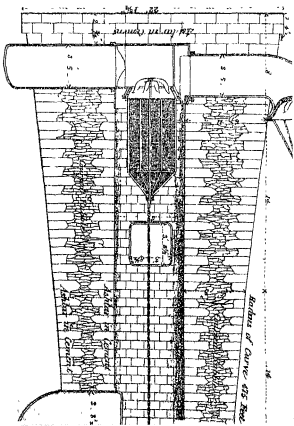
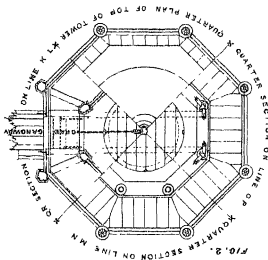
* *Vide* Appendix A.

passing with a velocity due to this pressure will be on the surrounding earth it is hardly necessary for me to explain. Material must be washed out from the dam by the water in its outward course, and after this has continued for a short time, the stability of the work must be destroyed. To repair a leak of this nature in the manner which I have adopted to render Nos. 2 and 3 Dams secure, will be not only attended with great risk, but impossible unless the supply to the town is stopped for several consecutive weeks. This fact, therefore, must be looked in the face, viz., that a time must come, sooner or later, when from the pipe under the embankment being worn away (as all iron ultimately wears away), and from there being no means of substituting another pipe in its stead, the inhabitants of Bombay, unless they furnish themselves with some other source of supply, will have to pass through a water famine.

The question is really a very serious one for the community. The arrangements for drawing water from the Vehar Lake are most imperfect. They consist of a masonry tower through the sides of which large iron pipes pass into the Lake, with copper gauze strainers over the mouths.* The strained water passes into the tower, at the bottom of which it enters the outlet pipe, whence it flows on to the town. The masonry of the tower leaks so badly, that I am told an attempt which was once made to examine the mouth of the outlet pipe at the bottom nearly resulted in the death of the diver, who was almost forced into the pipe by the quantity of water falling on him from above. It will thus be seen that to close the mouths of the strainers does not render the tower dry. It follows, therefore, that if a pipe bursts under the embankment, it will be impossible to discover the point of fracture by sending a man down the tower. The only thing to be done in this case will be to block up the mouth of the outlet pipe, so as to prevent any water entering it. Even this may be attended with difficulty, but if it is successful, the next thing will be to send a man into the pipe through the sluice valve at the outer foot of the embankment. If a real fracture of the pipe has taken place it will not perhaps be difficult for the man to discover its position, but if the leak were due to an imperfect joint, no examination of the pipes from the inside could enable a man to discover its locality. But in either case whether the iron is fractured, or whether the joints have separated, it will be impossible to repair the pipes from the inside. And let the pipes be re-

* *Vide* "Detail of Tower," Plate XVIII.

(Signed) H. Conybeare, C.E., F.G.S

T.M. Rozario Lith. Bombay

DETAILS OF TOWER
SHOWING
HOW THE WATER IS DRAWN OUT OF THE VEHAR LAKE.

Scale, ⅛ of an Inch to a Foot.

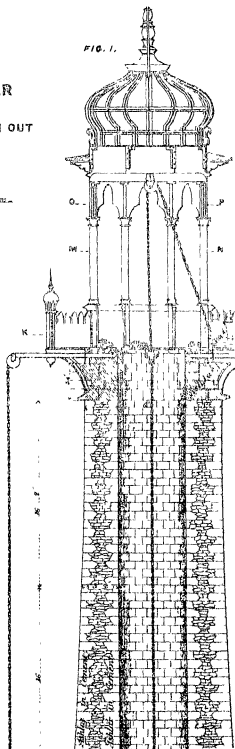
FIG. 1.

O P M N K

The Plugs and Strainers are lifted by means of a moveable Crab which is shewn in the Drawing

The Plugs and Strainers in Wall of Tower weigh about 1,430 lbs each, and as the Crab multiplies the power thirty two times 80 lbs on the crank axle will give 2560 lbs at the drum thus giving ample allowance for weight of chain & friction And as the work of one man turning an axle is 80 lbs at 8½ ft per second, he will be able to lift either Plug or Strainer at the rate of at about 8 ft per minute

To lift the Strainer at the bottom of the Well the Crab has to be moved into the position shewn in figs 1 & 2 and is there held down by bolts attached to the beams supporting the gangway.

To lift the Strainers outside the Tower and the Plugs the Crab is moved over the end of the chain that is fastened to the plug or

paired in any way whatsoever, the supply to the town must be shut off for weeks.

Under these circumstances I cannot but draw the attention of the Bench to the risk they are running in delaying to construct proper outlet works for the Vehar Lake,—works which should have no connection with any of the dams, and be so arranged that any defective portion may be repaired without difficulty or danger.

I have no reason to alter the plans which I suggested last year for the outlet system for the proposed Toolsee Reservoir I here again present them for the consideration of the Bench * All the works are completely under control, and any defective pipe may be taken out, and a new one substituted in its stead without trouble or risk. If the Bench desire it, detailed plans and estimates can be prepared to suit the system to the exact locality which may be decided upon for the new outlet works at Vehar, but it will be mere waste of time and labor to prepare these unless the Bench are determined to act in the matter

H. T.

APPENDIX A.

VEHAR DAM REPAIRS

Quantities and Cost of Work as completed on 1st July 1871.

	Quantity	Rate.		Total.		
DAM No. 2.	Brass of 100 c feet.	RS.	A	RS.	A.	P.
Earthwork, Excavated and Refilled, including Pumping, Shoring, Watering and Punning, &c., ...	3,618	4	0	14,472	0	0
Clay Puddle, Getting, Tempering, Carrying, Filling, including Watering and Punning,..	1,025	11	12	12,043	12	0
Pitching, taking off Pitching with Rubble Bedding, replacing do., and Setting Pitching, ...	squares 245	6	14	1,684	6	0
				28,200	2	0

* *Vide* "Plan of outlet works," Plate XVII., and Appendix B.

	Quantity.	Rate.		Total.		
		RS	A	RS	A.	P.
Carried forward, ...				28,200	0	0
DAM No. 3.	Brass of 100 c. feet					
Earthwork, Excavated and Refilled, including Pumping, Shoring, Watering and Punning, ...	7,049	4	0	28,196	0	0
Clay Puddle, Getting, Tempering, Carrying, Filling, including Watering and Punning,..	3,040	13	0	39,520	0	0
Pitching, taking off Pitching with Rubble Bedding, replacing do., and Setting Pitching, ...	squares 1,156	7	0	8,092	0	0
Supplying new Pitching with Rubble Bedding, ...	250	23	0	5,750	0	0
	Rupees, ..			81,558	0	0

GLOVER & Co.,
Contractors.

APPENDIX B.

Outlet Works designed for the Toolsee Reservoir.

[*Vide* Plate XVII].

THESE outlet works are designed with the view to enable the Engineer to repair any part of the work should it become damaged or wear away. The old plan of having a masonry tower standing in the water, and of carrying the outlet pipe from the bottom of this through the embankment is most objectionable. If the outlet pipe bursts, nothing can be done to repair it. Bombay at this present moment is in this happy predicament. The town is dependent on the security of a single pipe, which, passing through the bottom of a tower standing in the water, is carried under the main dam. If this pipe bursts it will be impossible to repair it, and the most serious consequences may follow such an event.

Now in the outlet works represented on the accompanying plan, the bursting, of the outlet pipe would be of no consequence whatever The stop valve would simply be closed, the defective pipe would then be removed and a new pipe substituted in its stead.

It will be seen that the proposed tower in these works is of a semicircular form, and that it is built on the side of a hill The only pressure that there can be against the tower is from the side of the lake, and the curved form of tower is best calculated to resist this.

Any number of inlet pipes can be inserted in the tower, and should one of these get out of order it has only to be plugged up, and when the water sinks below it the pipe can either be repaired or a new one put in.

Any number of inlet pipes may also be inserted on the upright pipe in the tower, and the water may be strained twice if desired—1st, By strainers over the mouths of the outer inlet pipes; and, 2nd, By strainers over the months of the inner inlet pipes

If the upright pipe or any of the inlets fixed to it get out of order the mouths of the outer inlet pipes can be stopped up by plugs, and the tower emptied of water After this is done workmen can descend into the dry chamber and carry out any repairs that may be required

The stop valve, if required, may be dispensed with, because if a burst occurs in the pipe laid along the tunnel, the water may be shut off from the pipe simply by lifting up the strainers, and putting plugs over the mouths of the inner inlet pipes.

The tunnel should be wide enough, not only for the number of pipes that may be required to give the necessary supply, but also to admit of a pipe being carried along it to replace one that may burst.

It is of great importance that the thickness of the masonry of the tower should be considerable, otherwise the water will creep through and the tower will not be water-tight.

H. T.

No. XXVI.

BULL'S HAND DREDGER.

Memo. on a Hand Dredger for Sinking Wells in Foundations or Bridges, invented and patented by W. BULL, ESQ., *Resident Engineer, Oude and Rohilkund Railway, Lucknow.* BY GEORGE WOODBRIDGE, ESQ., M. INST. C.E., *Officiating Superintending Engineer of the same line.*

WITH the accompanying sketch and descriptive mode of working the machine by the Inventor, very little explanation is required to understand this machine. It need only be said that it is intended to utilize the simple but well known principle which causes any tool or instrument to sink in sand of its own weight by a shaking, or up and down, motion; the fact of its doing this dispenses with any supplementary arrangement for forcing it into the material to be excavated, and has its result in the greatest possible economy of working.

The advantages of this Hand Dredger are.—

1st. It works just as well, and almost as quickly at 60 feet from top of platform of well as at 20 feet. [*Note.*—60 feet is not the limit of its power, but the greatest depth at which I have worked it].

2nd. That the cost of the machine with the apparatus for using it is small.

3rd. It is quickly rigged up or taken down and removed, an hour sufficing to take it from one well and get it to work on an adjoining one.

4th. Any ordinary blacksmith can construct it.

5th. It is so simple that (unlike a sand pump) it cannot easily get out of order, and if it does it can soon be repaired.

6th. The principle on which it works is so easily understood by ordinary coolies that they get into the way of working it after a very little practice.

7th. The annoyance and expense of divers are done away with.

During the greater part of the past season as many as 12 of these Dredgers have been at work in the wells of the bridge in course of construction over the Ram Gunga River, near Bareilly, then in my charge

The pier wells of this bridge are 14 and 16 feet in diameter, sunk through sand, with here and there thin strata of clay or kunker. The dredger has been used at other bridges on the Rohilkund line, but this Memo. gives only data derived from personal experience on the Ram Gunga Bridge

After having tried the sample dredger sent by the inventor, for trial, made more as soon as possible, and did away with all sand pumps. In fact the native contractors became so keen on what they called the "Belatee Jham," that they refused to use the sand pumps any longer.

The appliances required in addition to the dredger itself, will be shown in *Appendix A.*, or "method of working" the machine (by the inventor).

Appendix B. shows the comparison of the work done with it and the sand pump. The average of 14½ days' work gives the sinkage 1·27 per day for a 14 feet well, between the depths of 23 feet and 42 feet below water level. The sand pump, worked by a crab, only gives ·70 of a foot The average, however, for the last week, when the coolies working it (at first nearly new to the machine) had got used to it was 1·40 for the dredger to ·14 for the sand pump. A large 3 feet diameter sand pump holding 18 cubic feet, working with a steam hoist, might sink a well 3 feet in a day under the same circumstances, but against it should be placed the cost of the plant required, and the time spent in fitting up and removing the heavy apparatus necessary for working it.

Appendix C. shows the cost of plant necessary for working Bull's Hand Dredger, a two feet sand pump worked by a crab, and the largest sized sand pump worked by a steam hoist, apportioned daily to find the comparative cost of work done by the three machines.

Appendix D. shows the comparative cost of sinking by the three machines, (the performance of the large sized sand pump being taken at 3 feet,) and also that the work done by the hand dredger costs much less than that done by either description of sand pump, and as in a well

where a large sized sand pump could be worked two hand dredgers could be used, the quantity done should be in excess. Further the hand dredger will bring up the large lumps of sand stone or kunker so frequently met with in well foundations. Its greatest utility as compared with either description of sand pump will therefore be at once seen.

This machine will prove of very great assistance to anybody sinking wells through sand, of dimension large enough to admit of the dredger working in them, to any depth below water. Very little weight will be found necessary till about 40 feet depth is reached, after that weights will increase the speed of sinking.

Although not by itself adapted for clay, if the clay can be cut up or loosened it can be brought up by it to great advantage.

In this Memo. no mention is made of the first 20 feet below water level, as there is no difficulty in sinking to that depth or even somewhat deeper, but when the well has to be sunk 50 or 60 below water there comes the question—Which of the machines used for Well-sinking will give the quickest and cheapest results?

From my experience on the Rohilkund Lines, I am much in favor of this dredger, which has proved a very useful and handy implement.

G. W.

APPENDIX A.

Method of Working Bull's Hand Dredger.

A short chain four feet long, with a ring in the centre, should be attached by its ends to the rings on the chains working the machine. To the centre ring the chain for lowering and raising the machine is to be fixed, of a length greater or less according to the depth of the well. On the well two bullees should be fixed, with an iron block made fast to the junction. The bullees should not be less than 10 or 12 feet in length, stayed on either side to the ground. A wooden platform 6 feet × 4 feet composed of 1 inch sàl planks made fast to two under cross pieces, is also required, and two ¾-inch ropes, one made fast to the key keeping the jaws of the machine open, and the other to the centre ring in the short chain first mentioned.

In working, the machine is opened on the wooden platform and the

HAND DREDGER.

Scale

Key

Elevation, when set for lowering

Plan, Chains removed

key fixed. It is then lowered into the well, and on reaching the bottom the key is withdrawn; the rope attached to the latter should be coiled on one side of the platform ready for use. *A gentle pulling-and-giving motion* should now be applied with the rope attached to the centre ring of the short chain, *slowly at first,* and *as this peculiar motion causes the jaw of the machine to sink or cut into the sand, the strain should be increased,* till there is no further yielding to the pull which two men can put on the rope. The machine should then be raised and landed on the wooden platform. The operation of re-setting it for lowering, releases the sub-soil brought up and saves all trouble in emptying

The average quantity brought up, when the machine is properly worked, is 2 cubic feet, and in a well of 12 feet 6 inches diameter, 38 feet deep, there is no difficulty in working it 25 times in an hour

Three men on the top of the well, (not including those employed in removing the sand, which I find best done by contract,) and 15 men to pull, are required to work the hand dredger. The average performance per day in a 12 feet 6 inches well is 3 feet of sinkage for regular work, and practically speaking the depth of the well is of no consequence, the difference of time taken by the coolies walking 10 or 50 feet being inappreciable as compared with the time taken by each operation.

The dredger is principally intended for working in sand, but brings up anything which is cut up so that it can grip it. The motion of the wells being constant they should not require weighting; and, up to 35 feet, I have not found it necessary to weight the well.

W. B.

APPENDIX B

OUDH AND ROHILKUND RAILWAY, ROHILKUND LINE.

Comparative Statement showing the sinking done by a Sand Pump and Bull's Hand Dredger in a Well 14 feet diameter.

Bull's Hand Dredger	2 feet diameter Sand Pump.
The dredger was tested on a well that had been built, ... 50 feet.	The sand pump was tested on a well that had been built . 50 feet.
Sunk below surface, ... 30 "	Sunk below surface, ... 30 "
Depth below water, ... 20·4 "	Depth below water. .. .. 22·9 "
NOTE.—There were no weights on this well.	NOTE.—This well was weighted with rails and sand boxes.

No. of days	No of dredger lifted	Well sunk.	Remarks	No. of pump lifted.	Well sunk.	Remarks.
		ft				
½	60	0·5	Through sand, ...	9	..	Sand.
1	138	1·2	Ditto, ...	12	1·0	Do.
1	132	1 2	Ditto, ...	14	0·9	Do.
1	147	1·8	Ditto, ...	15	1·3	Do.
1	125	1·3	Sand with clay, ...	14	0·10	Do.
1	168	1·3	Ditto, ...	14	0·9	Do.
1	162	1·0	Layer proportion of clay,	15	1·8	Do.
1	130	0·11	Ditto, ...	13	0·11	Do.
1	155	1 8	Sand and clay, ...	14	0·11	Do.
1	200	1·6	Ditto, ...	14	0·6	Sand and silt.
1	162	1·9	Sand and silt, ...	14	0·6	Do.
1	150	1·11	Ditto { As the men became accustomed to the use of the dredger.	5	0 3	Pump out of water.
1	170	1 4		9	0·7	
1	190	1·4		11	0·4	
1	188	0 9	Clay and sand, ...	12	..	All empty.
14½	..	18 5			10 3	
		1·27	Average sinking per diem, ...		·70	Average sinking per diem.

APPENDIX C.

COMPARATIVE STATEMENT showing proportionate daily Cost of Apparatus for Well Sinking.

Bull's Dredger.	Cost.	Medium sized sand pump worked with a crab	Cost.	Large sized sand pump worked with a steam-hoist.	Cost.
1 Dredger, ...	45 0 0	1 Sand pump, ...	250 0 0	Steam hoist, ...	2000 0 0
75 feet, $\frac{3}{8}$"-chain, ...	20 0 0	1 Crab, ...	150 0 0	Large sand pump, ..	500 0 0
2 Poles for shear logs, ..	2 0 0	1 Double pulley, ...	25 0 0	3 Sheaved pulley, ...	30 0 0
2 Coils connecting rope, ..	10 0 0	1 Single „	15 0 0	2 „ „	25 0 0
2 Pieces of country rope, ..	3 0 0	1 Tressel frame with trolly,	110 0 0	1 „ „ .. .	15 0 0
1 Single sheaved pulley, ..	15 0 0	300 feet, $\frac{3}{8}$"-chain, ..	80 0 0	Tressel frame and trolly,	140 0 0
				300 feet, $\frac{3}{8}$"-chain, ...	80 0 0
Total cost, ..	95 0 0	Total cost, ..	630 0 0	Total cost, ..	2790 0 0
Deduct value when done, ..	30 0 0	Deduct value when done with, ...	250 0 0	Deduct value when done with, ...	1500 0 0
Balance, ..	65 0 0	Balance, ..	380 0 0	Balance, ..	1290 0 0
At 500 working days, per day, ...	0 2 1	At 500 working days, per day, ...	0 10 2	At 500 working days, per day, ...	2 9 3

MEMO.—As machinery when done with fetches as a rule very little in India, it will be fairest to divide the entire cost after deducting the probable realizeable amount, over the average length of time taken to complete a job of any magnitude or say two working seasons of 250 days each.

APPENDIX D.

STATEMENT to show comparative cost of Well Sinking by Bull's Hand Dredger, Small 2-feet Sand Pump and a Large 3-feet D° in a 14 feet Well between 20 and 50 below low-water.

Bull's Hand Dredger.

Item				
Cost of Machine, ...	0	2	1	per day
Repairs, new ropes, &c,	0	4	0	per day
18 Coolies, @ Rs. 0-3-0,	3	6	0	per day
Removing sand, ...	0	8	0	per day
Total, ..	4	4	1	
Daily average of work done. 1·4, ..				
Cost per foot of sinking,	3	0	7	
Add for stoppage from repairs, changing, &c., 25 per cent.* ..	0	12	1	
Total cost per foot, ..	3	12	8	
Nett daily performance, 1·06 foot.				

2 feet Sand Pump.

Item				
Cost of Machine, ..	0	10	2	per day
Repairs, &c, ...	0	4	0	per day
10 Coolies, @ Rs. 0-3-0,	1	14	0	per day
Removing sand, ..	0	4	0	per day
Total, ..	3	2	2	
Daily average of work done, ·70, ..				
Cost per foot, ..	4	7	8	
Add for stoppages, repairs, changing, &c., 50 per cent., ..	2	3	10	
Total cost per foot, ..	6	11	6	
Nett daily performance ·46 feet				

Large sized Sand Pump worked with Steam Hoist.

Item				
Cost of Machine, ..	2	9	3	per day
Repairs, &c., ..	0	8	0	per day
Fuel 25 mds, @ Rs 25,	6	4	0	per day
Enginemen, ..	0	10	0	per day
14 Coolies, @ Rs. 0-3-0,	2	10	0	per day
Removing sand, ..	1	0	0	per day
Total, ..	13	9	5	
Daily average, 3 feet.				
Cost per foot, ..	4	8	5	
Add for stoppages, repairs, changes, &c., 100 per cent., ...	4	8	5	
Total cost per foot, ..	9	0	10	
Nett daily performance 1 50 feet.				

* This is largely in excess of the actual loss of time, as each well made machine will work for months without any repairs.

No. XXVII.

ON THE ERRORS OF GRADUATION OF THE LIMBS OF INSTRUMENTS.

BY LIEUT. ALLAN CUNNINGHAM, R.E., *Hony. Fellow of King's College, London.*

It is a matter of great importance for purposes of angular measurement that the differences of readings on the graduated plates of surveying and astronomical instruments should be very approximately the projections (on the plane of the graduated plate) of the angular movement of the line of sight between the readings, and that one should know how to combine readings to the best advantage to eliminate the inevitable imperfections in the graduated plate itself. The necessity of, and the mode of doing this are seldom even casually alluded to in text-books on Surveying, and in no case have I seen the rationale explained, although every surveyor ought to be aware that he habitually uses the very means to eliminate them.

The errors due to imperfections in the plate itself are of several kinds.

1st Owing to defective centering, whether original or in consequence of unequal wear of the pivot, the axis of the pivot may not pass through the centre of the graduated limb

2nd. Owing to original deformity of the limb itself, *i. e.*, previous to graduation.

3rd. Owing to deformation of the limb (from any cause) subsequent to graduation.

4th. Owing to originally imperfect graduation.

It will be shown that the errors due to these four causes may be eliminated.

1st. Case.—By the use of two, four, or six verniers at 180°, 90° or 60° apart, even if the error be large, and also by the use of three verniers at 120° apart, when the error is small.

2nd. Case.—By use of three, four, or six verniers at 120°, 90°, or 60° apart, when the deformity is elliptic and small.

3rd. Case.—By use of three, four, or six verniers at 120°, 90°, or 60° apart, when the deformity is elliptic under certain laws, even if the error be large.

4th. Case.—By the use of several verniers, if the error be small.

It will be observed that the means indicated, viz., reading on several verniers is that in habitual use; and that, moreover, as the errors due to each cause are in a good instrument each *very small*, any combination of them may be eliminated by the same means.

On the character of the errors that can be eliminated by the use of several verniers.—The errors (in estimating angles) that can be eliminated by combining readings on several verniers must obviously be some function of the angle, and, moreover, some periodic function of period coincident with an entire sweep of the radius vector round the circumference; as if susceptible of indefinite increase with the angle, or even if a periodic function whose period differed from 2π, no combination of readings could eliminate the error.

The simplest periodic functions of period 2π are the trigonometrical functions. Since

$\sin(180°+A) = -\sin A$, and $\cos(180°+A) = -\cos A$, ...(1)

$\sin(2\times 90°+2A) = -\sin 2A$, and $\cos(2\times 90°+2A) = -\cos 2A$ ....(2)

$\sin(120°+A)+\sin(240°+A) = -\sin A$, and $\cos(120°+A)+\cos(240°+A) = -\cos A$ ....(3)

$\sin(2\times 120°+2A)+\sin(2\times 240°+2A) = -\sin 2A$, and $\cos(2\times 120°+2A)+\cos(2\times 240°+2A) = -\cos 2A$,(4)

$\sin(3\times 60°+3A) = -\sin 3A$, and $\cos(3\times 60°+3A) = -\cos 3A$ ....(5)

It follows—

(1). Errors proportional to either $\sin\theta$, $\cos\theta$, or to $l_1 \sin\theta + m_1 \cos\theta$, will be equal and opposite in readings on verniers diametrically opposite, and also (3) equal and opposite to the sum of errors in readings on two verniers 120° and 240° distant from the first vernier.

(2). Errors proportional to either $\sin 2\theta$, $\cos 2\theta$, or to $l_2 \sin 2\theta + m_2 \cos 2\theta$, will be equal and opposite in readings on two verniers 90° apart, and also (4) equal and opposite to the sum of errors in readings on two verniers 120° and 240° distant from the first vernier.

(5). Errors proportional to either $\sin 3\theta$, $\cos 3\theta$, or to $l_3 \sin 3\theta + m_3 \cos 3\theta$ will be equal and opposite in readings on verniers 60° apart.

It follows that taking the arithmetic mean of readings—

(1). On only two verniers diametrically opposite eliminates errors proportional to $l_1 \sin\theta + m_1 \cos\theta$.

(2). On four verniers at 90° apart, or (3) and (4) on three verniers at 120° apart eliminates errors proportional to $l_1 \sin\theta + m_1 \cos\theta + l_2 \sin 2\theta + m_1 \cos 2\theta$.

(1) to (5) On 6 verniers at 60° apart eliminates errors proportional to $l_1 \sin\theta + m_1 \cos\theta + l_2 \sin 2\theta + m_2 \cos 2\theta + l_3 \sin 3\theta + m_3 \sin 3\theta$.

N B—The verniers must be *truly* 180°, 120°, 90°, or 60° apart respectively, not as estimated on an incorrectly graduated plate, so that every pains must be taken to secure the accuracy of the angular splay of the verniers independently of the graduations on the limb.

The formulæ show that a pretty comprehensive class of errors can be eliminated by the use of three verniers, and a very extensive class by the use of six. Indeed, six verniers have apparently sufficed to remove all appreciable error in the largest plates or limbs.

The formulæ may, however, be made much more comprehensive.

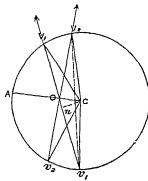
Since $E' = -E''$, if either $\sin n E' = -\sin n E''$, or $\tan n E' = -\tan n E''$, or $\cot n E' = -\cot n E''$; then if E', E'' be the errors in readings corresponding to two readings, it follows that if either E, $\sin n E$, $\tan n E$, or $\cot n E$, or any linear combination of them, such as $F(E) = (k_1 E + k_2 \sin n_2 E + k_3 \tan n_3 E + k_4 \cot n_4 E)$ be proportional to $l_1 \sin\theta + m_1 \cos\theta + l_2 \sin 2\theta + m_2 \cos 2\theta + l_3 \sin 3\theta + m_3 \sin 3\theta$ then the errors will *in general** be eliminated in taking the mean of readings on 6 verniers 60° apart, or if proportional to $(l_1 \sin\theta + m_1 \cos\theta + l_2 \sin 2\theta + m_2 \cos 2\theta)$ by using 4 verniers at 90°, or if proportional to $(l_1 \sin\theta + m_1 \cos\theta)$ by using 2 verniers diametrically opposed. But since if $\sin E' + \sin E'' + \sin E''' = 0$, or $\tan E' + \tan E'' + \tan E''' = 0$, or $\cot E' + \cot E'' + \cot E''' = 0$, it does not follow that $E' + E'' + E''' = 0$, therefore the use of 3 verniers at 120° apart will *not* necessarily eliminate this class of errors if of sensible magnitude.

But if the errors E', E'', E''' be all very small, then since a very small angle, its sine and tangent are all very nearly equal, it follows that if $(k_1 E + k_2 \sin E + k_3 \tan E)$ be proportional to $l_1 \sin\theta + m_1 \cos\theta +$

* Because the most obvious solution of $k_1 (E' + E'') + k_2 (\sin n_2 E' + \sin n_2 E'') + k_3 (\tan n_3 E' + \tan n_3 E'') + k_4 (\cot n_4 E' + \cot n_4 E'') = 0$, is $E' = -E''$, so that the errors would *in general* be eliminated there must be an infinity of other solutions, it is probable that they are all "instrumentally" impossible, though the author is not at present prepared to prove this but by far the most important case is that in which the error E is very small In this case, if $F(E) = (k_1 L + k_2 \sin n_2 E + k_3 \tan n_3 E)$, or if $F(E) = \cot n_1 E$, n_2, n_3, n_4 being all small, then $E' = -E''$ is the unique solution of the respective equations in E', E'.

$l_2 \sin 2\theta + m_2 \cos 2\theta$), E being very small, then the error will be eliminated by taking the mean of readings on 3 verniers 120° apart.

CASE 1.—*Excentricity of the pivot.*

Let v_1, V_1, v_2, V_2, be the graduated plate (supposed circular), C its centre, O the foot of the axis of the pivot of the telescope which carries with it the verniers which should be so placed (*by the maker*) that the line joining the zeros at V_1, v_1 of an opposing pair should pass through O. Suppose the telescope to be turned through an angle $V_1 O V_2$, then the angle that is *to be arrived at* is V_1OV_2, whereas the angle obtained as the difference of *readings* on the vernier V is V_1CV_2 and on the opposing vernier v is v_1Cv_2. Join v_1V_2.

Now the angle $V_1CV_2 = 2\ V_1v_1V_2$, and $v_1Cv_2 = 2\ v_1V_2\,v_2$.

$$\therefore\ V_1CV_2 + v_1Cv_2 = 2\ (V_1\,v_1V_2 + v_1V_2\,v_2) = 2\ V_1\,OV_2$$

i. e., the required angle V_1OV_2 is the mean of the angles V_1CV_2, v_1Cv_2 obtained as the differences of readings on two opposing verniers, (provided the line joining their zeros passes through O the foot of the axis of the pivot,) even though the excentricity be considerable.

If the error in *reading* at V_1 be estimated from the radius through CO, then the error is difference of AOV_1 the required, and ACV_1 the read angle, *i. e*, the error is $AOV_1 - ACV_1 = CV_1O$. call this E, and let

$AOV = \theta\ \therefore\ \sin\ E = \frac{Cn}{CV_1} = \frac{CO \sin COn}{CV_1} = \frac{CO}{r}.\ \sin\theta$, *i. e.*, sin E is proportional to $\sin\theta$.

Hence it follows that this error is of the class which when *considerable* can only be eliminated by using two, four, or six verniers equally distant in arc, and when *very small* is also eliminated by using three verniers. Since the angle AOV_1 is obtained correctly by taking the mean of readings on V_1, v_1; and similarly also the angle AOV_2, it follows that the angle V_1OV_2 will be obtained correctly even if the whole plate be

shifted between the times of observing V_1, V_2, so that its centre remains on the fixed line OA, provided the point O remain steady.

The above result has been obtained on the supposition that the plate is truly circular.

CASE 2.—*Original Ellipticity of the Limb.*

The plate which is to be graduated is made as nearly circular as possible by turning in a lathe. Slight defects are likely to ensue in the turning from the following causes :—

1st The plate may be slighly excentrically chucked.

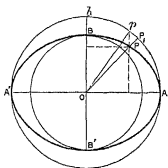
2nd. The plane of the plate may be not quite perpendicular to its axis of revolution.

3rd. The tool or the plate, or both, may not remain quite steady during the revolution.

The first two causes would, whether separately or combined, cause the plate to be turned elliptic, and the third would do the same, if the rate of deviation from the mean position were uniform, and of period the same as one revolution of the plate.

It may, therefore, be assumed that the *most probable* form of a plate intended to be circular is a very slightly excentric ellipse.

Suppose then, that the plate is before graduation, the very slightly excentric ellipse AB, A′ B′. The graduation is performed by subdividing the *length* of the circumference into equal lengths.*

It will be convenient *for the present* to measure arcs on the ellipse from one end B of the minor axis BB′ (as if B were the zero of graduation). Let P be any point on the ellipse, p OA the excentric angle corresponding to P, BOP $= \theta$, $bOp = \phi$, AA′ $= 2a$, BB′ $= 2b$, $e^2 = 1 - \frac{b^2}{a^2}$ a fraction so small that e^4, e^6, &c., may be neglected. Then the value of the angle BOP obtained by reading the vernier at P will be measured by the ratio of the elliptic

* See the Article "Graduation" in Charles Knight's English Cyclopædia, Arts and Science Division.

arc BP to the whole circumference of the ellipse, instead of by (as it should be) the ratio of the circular arc bP_1 to the whole circumference of the same circle, so that the error will be the difference of the ratios $\frac{\text{length of arc BP}}{\text{Circum. of ellipse}}$ and $\frac{\text{length of arc } bP_1}{\text{Circum. of circle}}$.

Now, the length of arc BP $= a\int_0^\phi \left(1 - e^2 \sin^2 \phi\right)^{\frac{1}{2}} d\phi$

$$= a\int_0^\phi \left(1 - \frac{e^2}{2} \sin^2 \phi - \text{terms involving } e^4, e^6, \&c.\right) d\phi$$

$$= a\int_0^\phi \left(1 - \frac{e^2}{2} \sin^2 \phi\right) d\phi \text{ very approximately, } e \text{ being very small.}$$

$$= a\,\phi - \frac{e^2 a}{2}\left(\frac{\phi}{2} - \tfrac{1}{2} \sin \phi \cos \phi\right) = a\left\{\left(1 - \frac{e^2}{4}\right)\phi + \frac{e^2}{8} \sin^2 \phi\right\}.$$

Similarly the length of the circumference of the ellipse

$$= 4a\int_0^{\frac{\pi}{2}} \left(1 - \frac{e^2}{2} \sin^2 \phi\right) d\phi$$

$$= 2\pi\, a\left(1 - \frac{e^2}{4}\right) \text{ very approximately.}$$

Also the length of arc $bP_1 = a\theta$, and of circular circumference $= 2\pi a$.

To compare these, the expression for the elliptic arc BP, which is now in terms of ϕ must be changed to its value in terms of θ.

Sinc $\phi = bop$ is the complement of pOA the excentric angle corresponding to POA which is the complement of θ, therefore

$$\tan \phi = \frac{b}{a} \tan\theta = (1 - e^2)^{\frac{1}{2}} \tan\theta.$$

Now if $\delta\theta$ be the very small angle by which θ differs from ϕ,

Then $\delta\theta = \tan \delta\theta$ (very nearly) $= \tan(\theta - \phi) = \frac{\tan\theta - \tan\phi}{1 + \tan\theta \tan\phi}$

$$= \left\{1 - (1 - e^2)^{\frac{1}{2}}\right\} \tan\theta . \left\{1 + (1 - e^2)^{\frac{1}{2}} \tan^2\theta\right\}^{-1}$$

$$= \left\{1 - \left(1 - \frac{e^2}{2}\right)\right\} \tan\theta . \left\{1 + \left(1 - \frac{e^2}{2}\right) \tan^2\theta\right\}^{-1}$$

very nearly, e being very small

$$= \frac{e^2}{2} \tan\theta . \left(\sec^2\theta - \frac{e^2}{2} \tan^2\theta\right)^{-1} = \frac{e^2}{2} \sin\theta \cos\theta \left(1 - \frac{e^2}{2} \sin^2\theta\right)^{-1}$$

$$= \frac{e^2}{4} \sin 2\theta \text{ very nearly.}$$

Hence the length of arc BP which was shown

$$= a\left\{\left(1 - \frac{e^2}{4}\right)\phi + \frac{e^2}{8} \sin 2\phi\right\} \text{ becomes}$$

$$\text{BP} = a\left\{\left(1 - \frac{e^2}{4}\right)(\theta - \delta\theta) + \frac{e^2}{8} \sin(2\theta - 2\,\delta\theta)\right\}$$

$$= a \left\{ \left(1 - \frac{e^2}{4}\right)(\theta - \delta\theta) + \frac{e^2}{8} (\sin 2\theta \,.\, \cos 2\delta\theta - \cos 2\theta \, \sin 2\delta\theta) \right\}$$

$$= a \left\{ \left(1 - \frac{e^2}{4}\right)(\theta - \delta\theta) + \frac{e^2}{8} (\sin 2\theta - 2\delta\theta \,.\, \cos 2\theta) \right\},$$

$\cos 2\delta\theta$ being very nearly $= 1$, and $\sin 2\delta\theta$ being very nearly $= 2\delta\theta$,

$$= a \left\{ \left(1 - \frac{e^2}{4}\right)\left(\theta - \frac{e^2}{4} \sin 2\theta\right) + \frac{e^2}{8} \left(\sin 2\theta - \frac{e^2}{2} \sin 2\theta \cos 2\theta\right) \right\},$$

(substituting for $\delta\theta$)

$$= a \left\{ \left(1 - \frac{e^2}{4}\right)\theta - \frac{e^2}{8} \sin 2\theta \right\} \text{ very nearly}$$

$$\therefore \frac{\text{Length of elliptic arc BP}}{\text{Circumference of ellipse}} = \frac{a \left\{ \left(1 - \frac{e^2}{4}\right)\theta - \frac{e^2}{8} \sin 2\theta \right\}}{2\pi a \left(1 - \frac{e^2}{4}\right)}$$

$$= \frac{\theta}{2\pi} - \frac{e^2 \sin 2\theta}{16\pi a \left(1 - \frac{e^2}{4}\right)}$$

$$\text{Also } \frac{\text{Length of circular arc } bP_1}{\text{Circumference of circle}} = \frac{a\theta}{2\pi a} = \frac{\theta}{2\pi}.$$

$\therefore$ Error in angle BOP $= - e^2 \sin 2\theta \div 16\pi a \left(1 - \frac{e^2}{4}\right)$, *i. e.*, the error varies as $\sin 2\theta$, and is therefore of the class that are eliminated by reading on either three verniers 120° apart, or on four verniers 90° apart.

These results have been obtained on the supposition, (most convenient at the time,) that the end B of the minor axis was the zero of graduation. If however the zero of graduation be (as is most likely) at some other point Q on the curve, then *every reading* will be also affected by the additional error due to the ellipticity of the arc QB, but as this will be the same for every reading, it will disappear in the values of *angles* because these can only be obtained as *differences of readings*

Hence it follows that if the original ellipticity be very small, all error due to ellipticity will be eliminated from the final values of angles by taking the mean of readings on three verniers at 120° apart, or four verniers at 90° apart; the zeros of the verniers should be set *by the maker* to subtend a right angle (not 90° as measured on the elliptic arc) at the centre of the curve.

This result has been obtained for the particular case of the ellipse on account of its importance as the most probable form of curve. A precisely similar reasoning would show that any slightly eccentric curve

resembling an ellipse whose arc could be represented by the formula

$$s = a\ \{\ k\theta - e\,(k_1' \sin\theta + k_1'' \cos\theta) - e^2\,(k_2' \sin 2\theta + k_2'' \cos 2\theta) - e^3\,(k_3' \sin 3\theta + k_3'' \cos 3\theta) - \&c.,\}$$

where e is a very small fraction such that e^4, e^5, &c, may be neglected, where θ is the *vectorial angle* BOP, would produce an error in the angle BOP proportional to $l_1 \sin\theta + m_1 \cos\theta + l_2 \sin 2\theta + m_2 \cos 2\theta + l_3 \sin 3\theta + m_3 \cos 3\theta$, which it has been proved could be eliminated by using 6 verniers, and if e be so small that e^3 may be neglected, then $l_3 = 0$, $m_3 = 0$, and the error then could be eliminated by using 3 or 4 verniers.

A very large class of curves of the higher orders are obviously included in this generalized formula, which expresses the relation between the arc and vectorial angle: the differential polar equation which would lead to this is $dr^2 + r^2\,d\theta^2 = ds^2$.

CASE 3.—*Alteration of the Shape and Size of the Plate.*

There are certain laws under which even *considerable* alteration may take place in the graduated plate without affecting the resulting values of angles.

(1). *Simple radial alteration*, viz., that in which the lengths only of some or all of the semi-diameters are affected: as this does not affect the angular position of any semi-diameter, it does not affect the readings of the limb. It is worthy of notice that the readings will not be affected, even if this alteration be extensive and *irregular*.

(2). *Simple alteration* of the size of the curve (if originally slightly elliptic), *such that the change of length of arc may be proportional to its length.* Referring to the article on "Original Ellipticity," (Case 2), if the change per unit of arc be k, then the change in the elliptic arc BP is kBP, and the change in the elliptic circumference is $k \times$ circumference, therefore the elliptic measure of the angle BOP in the altered plate is $\frac{(1 + k) \times \text{original arc BP}}{(1 + k) \times \text{original circumference}}$, which is the same as before, that is to say, the semi-diameter BP has suffered no change of angular position. Hence the readings are not affected by this change. This is evidently a case of simple radial alteration.

(3). *Simple translation*, viz., that in which the whole plate is shifted (without rotation, and without relatively straining its parts) in its own plane. If the foot of the axis of the pivot of the telescope partake of the

motion, the readings will not be affected: but if it do not, it will become excentric, and all readings will be affected by the error of excentricity. It has been already shown (Case 1), how the values of angles are nevertheless obtained correct in this case.

(4). *Simple rotation* about the centre, viz, that in which the whole plate is rotated about its centre (without straining its parts relatively) in its own plane. as this simply shifts every semi-diameter through equal angles, it affects every reading by an equal amount, and does not affect the values of angles which can only be obtained as differences of readings.

(5). *Any combination of the above.* The same processes that eliminated errors of angles in the separate cases will when combined eliminate the accumulated errors. It should be noticed that change under conditions (1) and (2) may occur at anytime even *between* the times of reading different verniers without affecting the readings, also that a shifting of the whole plate along the line joining its centre to the foot of the pivot may take place under condition (3) between each observation, (but not between the set of readings on the set of verniers required to complete a simple observation,) without affecting the deduced angles, but that it is essential under condition (4) that the plate should remain steady during the whole of a series of observations.

Unfortunately this rotation of the plate between observations is the most likely of all to occur in the act of turning the telescope from one object to another, especially in a theodolite whose lower plate is only held by friction by a clamp. no combination of readings on verniers could eliminate this it is eliminated by taking an even number of rounds of angles, alternately from right to left.

Elliptic Deformation of the Plate.—The changes (1) to (5) in the plate above considered have not affected the relative angular positions of the semi-diameters; changes of the latter class might be called deformations; they are much more serious in their effects on readings than the previous class.

The law of deformation of a slightly excentric elliptic plate (which will include the case of a circular plate) into an elliptic curve of it may be different and even sensible excentricity will now be investigated.

Referred to its axes the equation of the original ellipse is of course of form $ax^2 + by^2 = 1$.

Then if X, Y be the co-ordinates of the point P in the new ellipse to

which any point p in the original whose co-ordinates are x, y are shifted by deformation, and if δX, δY be the change in the co-ordinates, then $x = X + \delta X$, $y = Y + \delta Y$

$\therefore a(X + \delta X)^2 + b(Y + \delta Y)^2 = 1$, is the equation of the new curve, δX and δY being at present unknown functions probably of the co-ordinates. Now as the new curve is to be elliptic, δX and δY must be of such forms that in the result the co-ordinates X, Y are not involved with negative indices, nor with positive indices higher than the square, so that δX must be of form $a_0 + a_1 X + b_1' Y$ and δY ,, $b_0 + b_1 Y + a_1' X$ where the functions whose type is a, b must be constant, *i e*, independent of the co-ordinates, and also constant for every point of the curve.

The equation of the new curve is

$$(a\overline{1 + a_1}^2 + ba_1'^2) X^2 + 2\,(ab_1'\,\overline{1 + a_1} + ba_1'\,\overline{1 + b_1})XY$$
$$+ (ab_1'^2 + b\,\overline{1 + b_1}^2)\,Y^2 + 2\,(aa_0\,\overline{1 + a_1} + bb_0\,a_1')X$$
$$+ 2\,(bb_0\,\overline{1 + b_1} + aa_0\,b_1')\,Y = 1$$

which represents some conic section, and necessarily either a circle, or ellipse, because the changes δX, δY are supposed finite, no finite deformations could deform a limited curve (as an ellipse) into a hyperbola or parabola which have infinite branches.

Moreover, as in practice the changes δX, δY are very small, the resulting curve will be only slightly excentric, as no small deformations could convert the originally very slightly excentric ellipse into one of great excentricity.

Interpreting the law of deformation, it appears that the original curve will be converted into an ellipse, if the changes in either or both of the co-ordinates be

(1) Independent of the co-ordinates viz., $\delta X = a_0$, $\delta Y = b_0$.

(2) Simple direct functions of the same co-ordinate, viz., $\delta X = a_1 X$, $\delta Y = b_1 Y$.

(3) Simple direct functions of the other or of both co-ordinates, viz., $\delta X = b_1' Y$, $\delta Y = a_1' X$.
Or $\delta X = a_1 X + b_1' Y$, $\delta Y = b_1 Y + a_1' X$.

(4) Any combination of these.

On comparing the equations of the new and old curves, it is seen that —(1); The only terms of the first order in X and Y are introduced solely by the first condition and also, that this condition affects no other

terms: consequently, this condition simply causes a translation of the whole plate in its own plane without affecting its shape or causing rotation. The effect of this change has been already fully considered; as it in no way affects (2) or (3), it need not be re-considered: it is in fact not a deformation.

(2). The effect of the second condition is simply to alter the co-efficients of X^2 and Y^2, and therefore to alter the lengths of the axes (without rotating them), and consequently in general the excentricity also: the angular positions of all semi-diameters relatively to the axes are altered (this may easily be seen by laying the curve down on paper).

(3.) The effect of the third condition is to introduce the term XY and also generally to alter the co-efficients of X^2 and Y^2. The axes of the new curve are in consequence different in position from the original axes, and there is in general an alteration in the size and shape of the curve, and also in the relative angular position of all semi-diameters.

The proof shows that deformation of an ellipse into an ellipse takes place (if the changes are algebraic functions of the co-ordinates) only when the changes in the co-ordinates are linear functions of the co-ordinates, viz., $\delta X = a_1 X + b_1' Y$ and $\delta Y = b_1 Y + a_1' X$. It is, probable, elliptic deformation might also take place under a great variety of transcendental laws of change: it has already been shown that if the change in length of arc be proportional to the length of arc (which change is of course a transcendental function of the co-ordinates) no angular deviation of the semi-diameters takes place; the graduation of the elliptic plate by *equal subdivision of its circumference* is moreover equivalent to deformation which is a transcendental function of the co-ordinates, this has been already considered, but the general case of elliptic deformation is too wide a subject to be further discussed here.

For purposes of angular measurement, the angular deviation $\delta\Theta$ of the semi-diameters is the only important one: the change *of form* of curve was however much more easily investigated by using rectangular co-ordinates. Changing now to polar co-ordinates, let R,Θ corresponding to X, Y be the co-ordinates of the point P of the new curve to which the point p of the original whose co-ordinates are r,θ (corresponding to x,y) is shifted in deformation. Also let δR, $\delta\Theta$ be the differences between the polar co-ordinates (corresponding to δX, δY)

Now $\delta\Theta = \left(\frac{d\Theta}{dX}\right).\,\delta X + \left(\frac{d\Theta}{dY}\right).\,\delta Y$, and $\delta R = \left(\frac{dR}{dX}\right).\,\delta X + \left(\frac{dR}{dY}\right)\delta Y$

And since $\Theta = \tan^{-1}\frac{Y}{X}$ and $R = \sqrt{X^2 + Y^2}$

$$\therefore \left(\frac{d\Theta}{dX}\right) = -\frac{Y}{R^2}, \left(\frac{d\Theta}{dY}\right) = \frac{X}{R^2}, \left(\frac{dR}{dX}\right) = \frac{X}{R}, \left(\frac{dR}{dY}\right) = \frac{Y}{R}$$

$$\therefore \delta\Theta = \frac{1}{R^2}\left(X\,.\,\delta Y - Y\,.\,\delta X\right), \text{ and } \delta R = \frac{1}{R}\left(X\,.\,\delta X + Y\,.\,\delta Y\right)$$

$$\delta\Theta = \frac{1}{R^2}\left\{ X\left(b_1 Y + a_1' X\right) - Y\left(a_1 X + b_1' Y\right) \right\},$$

$$= a_1' \cos^2\Theta + \frac{a_1 + b_1}{2}\sin 2\Theta - b' \sin^2\Theta,$$

$$= \frac{1}{2}\left\{\overline{a_1' - b_1'} + \overline{a_1 + b_1}\sin 2\theta + \overline{a_1' + b_1'}\cos 2\theta \right\},$$

$$\delta R = \frac{1}{R}\left\{X\left(a_1 X + b_1' Y\right) + Y\left(a_1' + b_1' Y\right)\right\}$$

$$= \left\{ a_1 \cos^2\Theta + \frac{a_1' + b_1'}{2}\sin 2\Theta + b_1 \sin^2\Theta \right\}$$

$$= \frac{R}{2}\left\{\overline{a_1 + b_1} + \overline{a_1' + b_1'}\sin 2\theta + \overline{a_1 - b_1}\cos 2\theta \right\}$$

The change $\delta\theta$ will be the error in the angle Θ measured from the end of the major axis of the new ellipse; being of form $a + l_2 \sin 2\theta + m_2 \cos 2\theta$, the periodic portion of it will be eliminated (as was shown in the article on the character of these errors) by taking the mean of readings on two verniers 90° apart, *i. e.*, on a set of 3, 4, or 6 verniers.

The constant portion $a = \frac{a_1' - b_1'}{2}$ of the above error, and also the error due to the arc between the zero of the graduation and the end of the major axis will affect all readings alike, and will therefore disappear from the value of angles which can only be obtained as differences of readings.

CASE 4.—*Errors due to original defective graduation.*

The original graduation of large plates is effected by subdividing into sixteen as nearly as possible equal parts, the *length* of the circumference, viz., by running a wheel round the plate which makes just 16 revolutions in a revolution round the plate: such extreme care is taken in marking each complete revolution, and in making allowance for slipping of one disc on the other, that it may be assumed that such small errors as do creep into the resulting graduation are either irregular, or else functions which are practically evanescentat any rate at 16 points equidistant round the curve; and attaining a maximum in the intervals.

It is extremely probable that small errors which are irregular, and

also errors which have *many* maxima and minima (points of practical evanescence) will be practically eliminated by taking readings in several parts of the plate, *i. e.*, by using several verniers, but the author is not aware that the most probable defects of graduation lead to small errors, which are either directly proportional to, or such that

$F(E) = k_1 E + k_2 \sin n_2 E + k_3 \tan n_3 E$ is proportional to $l_1 \sin\theta + m_1 \cos\theta + l_2 \sin 2\theta + m_2 \cos 2\theta + l_3 \sin 3\theta + m_3 \sin 3\theta$, *i. e.*, which are certainly and entirely eliminated by the use of 6 verniers.

SUMMARY OF RESULTS.

It has now been shown

(1). That if the plate be truly circular, errors due to excentricity of pivot, even if considerable, and even if the plate suffer a considerable translation in the direction of the excentricity between the observations of each point are eliminated by the use of any even number of verniers diametrically opposed.

(2). That if the plate be originally an ellipse of very slight excentricity, provided the graduation on it be such as to sub-divide the *length* of the circumference equally, all errors will be eliminated by the use of three or four verniers 120° or 90° apart.

(3). That if the plate (even if originally slightly elliptic) be deformed into an ellipse (even of considerable excentricity) by changes (even if considerable) in the co-ordinates of every point which are any linear function of either or both, all errors will be eliminated by the use of three or four verniers at 120° or 90° apart.

(4). That it is extremely probable that very small errors of original defective graduation will, if irregular, or if of frequent periodicity (*i. e.*, if passing through their period many times in the circumference) be practically eliminated by reading on several verniers.

(5). That in general any error E such, that the function

$F(E) = k_1 E + k_2 \sin n_2 E + k_3 \tan n_3 E + k_4 \cot n_4 E$ is proportional to $l_1 \sin\theta + m_1 \cos\theta + l_2 \sin 2\theta + m_2 \cos 2\theta + l_3 \sin 3\theta + m_3 \cos 3\theta$, is eliminated by the use of 6 verniers.

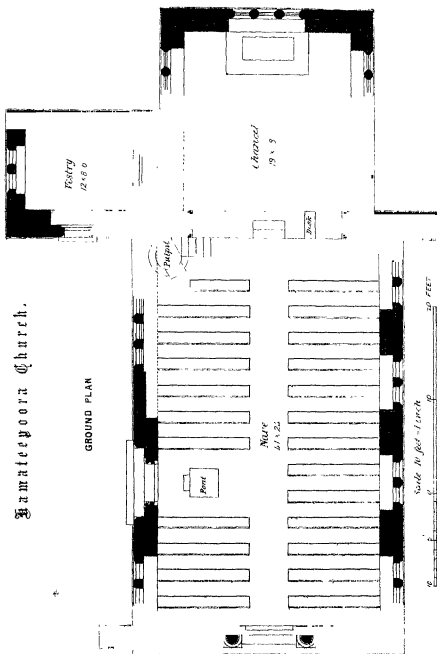
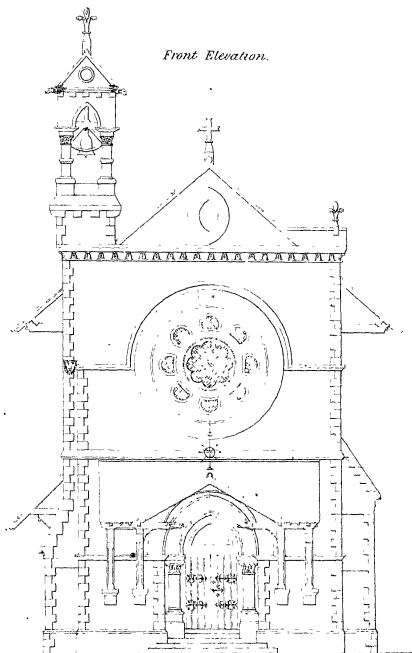
But if all these sources of error exist together, as is probably the case in practice, the errors will not be eliminated unless very small (as they really are in a good instrument), in which case by the theory of the superposition of small motions, they will still be eliminated.

No. XXVIII.

KAMATEEPOORA CHURCH.

By J. H. E. Hart, Esq., C.E., *Superintending Engineer, Bombay.*

Description.—The Kamateepoora Church is situated in the midst of the native houses in the town of Bombay, near Byculla, and is intended for the use of Native Converts. It was designed by Mr. W. Emerson, Architect, and built by Mr. Stevens, Assistant Executive Engineer, under Colonel Fuller's superintendence. The style of architecture is early French Gothic of the 12th century. The nave is 41 × 24 feet, chancel 19 × 18 feet, and vestry 12 × 8 feet 6 inches. The nave is lighted by four two-light and four cinquefoil clerestory windows on the south; one two-light, one three-light, and two cinquefoil clerestory windows on the north; and one large circular rose on the west. The chancel in lighted by one two-light window on the north, one on the south, and one three-light on the east. The windows are iron framed, glazed with amber colored church glass, set in lead, and supplied from England on indent. Between the nave and chancel is a handsome Porebunder stone arch, supported on carved corbels. There is a wide Porebunder stone arch on the north side, having a large three-light window built in, which will be utilized for the north transept, should further extension be deemed necessary. The walls are of rubble stone and chunam masonry faced with blue basalt irregularly fitted rubble neatly pointed. The quoins, cornices, strings, mullions, window heads, and interior arches are in Porebunder stone; the exterior main arches in Coorla stone. The roofs are double, and of novel construction, and very effective for ventilation. Between each of the principals are placed laminated beams cut to the curve of the inner roof so as to

Kamateepoora Church.
GROUND PLAN
Vestry
12 × 8 0
Chancel
19 × 9
Pulpit
Desk
Font
Nave
41 × 22
Scale 10 feet = 1 inch
10
5
0
10
20 FEET
PLATE XX

Hamateepoora Church.

Scale 10 feet = 1 inch

10 5 0' 10' 20' FEET.

take boarding and pannels, which are pierced with geometrical patterns to form the ventilators, thus affording direct communication with the ventilators immediately under eaves of the roof. There is an air space all round between the upper tiled and the lower curved roofs, which ensures a thorough system of ventilation so essential in an Indian climate.

The building contains 82,000 cubic feet, and the cost being Rs. 38,981, the rate is 7 annas and 7 pies per cubic foot.

Half the cost is met by the Society for the Propagation of the Gospel.

ABSTRACT OF COST

c. ft.		Rs.
10,448	Excavating foundation, at Rs. 1-11-2 per 100, ...	177
2,320	Concrete foundation, at Rs 25-12-9, per 100, ...	599
7,700	Rubble stone and chunam foundation, at Rs. 23-3-6, per 100, ..	1,788
1,525	" plinth, at Rs. 27, per 100, ...	412
s. ft.		
332½	Blue basalt facing to plinth at Rs 25 per 100, ...	83
c. ft.		
123¼	Coorla cut stone coping to do., at Rs 3-9-6 per cubic foot, ..	452
48¾	Coorla cut-stone quoins to do., at Rs. 3-5-3 per cubic foot, ..	162
76 78½	Filling in floors, at Rs 3-0-8 per 100, ...	234
s. ft.		
47 60	Stone pavement with bedding, at Rs. 131-12-7, per 100, ..	63
800$\frac{1}{10}$	Asphalte, &c., with bedding, at Rs. 45-3-1 per 100, ...	362
569	Minton tiled flooring do., at Rs. 136-15-3 per 100, ...	779
c. ft.		
176 3	Blue basalt cut-stone steps, at Rs. 2-9-1 per cubic foot, ...	453
13,982	Rubble stone and chunam walls, at Rs 27-7-2 per 100, ..	3,838
s. ft.		
4,969	Irregular blue basalt facing, at Rs. 15-2-4 per 100, ...	753
5,166	Chunam plaster, at Rs 12-8, per 100, ...	646
c. ft.		
363⅞	Coorla cut-stone archwork, at Rs. 3-12 per cubic foot, ...	1,365
749½	Brick and chunam arches, at Rs 45-10-2 per 100, ...	410
320½	Porebunder stone mullions, at Rs. 3-8-8 per cubic foot, ...	1,137
s. ft.		
510	P. B stone strings to windows, at Rs. 3-10-1 per cubic foot, ..	1,853
c. ft.		
290	Porebunder stone arch work in window heads, at Rs. 3-12-8 per cubic foot, ...	1,101
6¾	Cut-stone bases to columns, at Rs. 4 per cubic foot, ...	27
s. ft.		
234	Extra labor for roll moulding, at Rs. 0-2-6 per sup. foot, ..	37
No.		
2	Hemmygur stone caps, at Rs. 62-11, each, ...	125

	ABSTRACT OF COST. *(Continued).*	RS.
c. ft.		
73	P. B stone sills to windows, at Rs. 13-4 per cubic foot, ..	237
838⅓	„ „ quoins and jambs, at Rs 3-0-9 per cubic ft,	2,619
62½	P. B. stone cornice below tie-beams, at Rs 3-0-3 per cubic foot,	189
469½	P B stone arch work over do, at Rs 3-8-10 per cubic foot, ..	1,669
22⅓	„ „ corbels in front, at Rs. 3-9-7 per cubic foot, ..	106
6	„ „ „ north side, at Rs 3-8 per cubic foot, ..	21
No.		
2	Red stone shafts, at Rs 47-1 each, ...	94
c ft.		
122⅓	Corbels, large, with bases, at Rs 4-1-5 per cubic foot, ...	21,791
2½	„ small, at Rs. 3-8, per cubic foot,..	9
32¼	Blue basalt stone coping, at Rs. 3 per cubic foot, ...	97
52½	Brick and chunam walls, at Rs 50 per 100, ...	26
No.		
9	B. P. stone caps to buttresses, at Rs 4, each, ...	26
c. ft.		
64·⅓	Coorla cut-stone corbels, at Rs 4-8 per cubic foot, ...	289
s. ft.		
120 16	Teak doors, complete, at Rs. 3-7-3 per superficial foot,.. ...	415
567	Glazed windows, do, at Rs 6-4 per superficial foot, ...	3,544
sq. ft.		
4,137	Roof complete, at Rs. 130-3-1 per square foot, ...	5,386
c. ft.		
61	P B stone gable cornice, at Rs 3-4-10 per cubic foot, ...	211
12¾	„ finials, at Rs. 2-10-9 per cubic foot, ...	36
No.		
4	Teak trusses, complete, at Rs. 277-14-9 each, ...	1,112
	Tympanum and vesica, ...	712
	West and north porches, ...	1,075
	Belfry tower,..	2,102
	Total, Rs, ...	37,363
	FURNITURE.	
	Pulpit, at Rs	200
	Reading desk, at Rs	45
	Altar railings, at Rs.	261
	Font, at Rs.	158
	Benches, large, at Rs.	615
	„ small, at Rs.	78
	Altar tables, and 2 chairs, ...	160
	Total, ...	1,518
	Contingencies and extra establishment, ...	1,619
		40,500

The Pulpit, Reading Desk, Font are of Carved Porebunder stone. The Altar Rail of Teak or Iron.

Kamateepoora Church.
North Elevation.
Scale, 14 feet = 1 inch
10 5 0 10 20 FEET

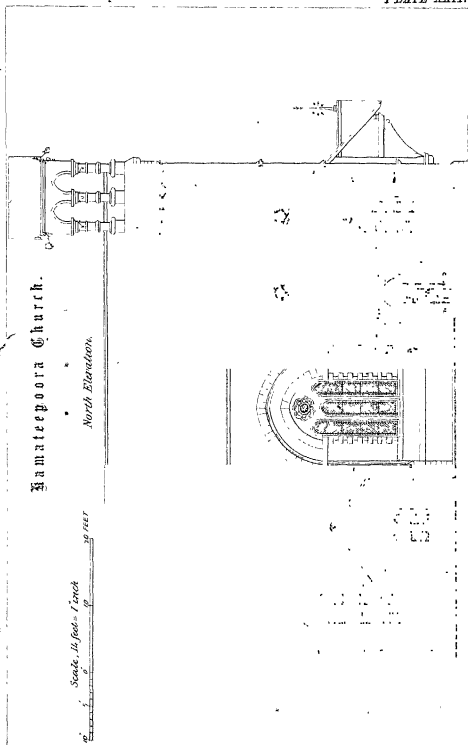
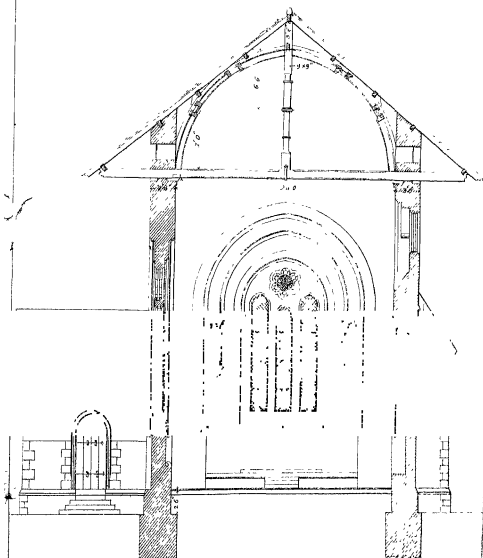



PLATE XXIII.
Kamateepoora Church.
Cross Section
Scale 10 feet = 1 inch
10
5
0
10
20 FEET

No. XXIX.

AKOLA IRRIGATION PROJECT.

A Precis of the Akola Project for Irrigation and Water Supply. By LOWIS JACKSON, ESQ., C.E., *Exec. Engineer, Berar Irrigation.*

THE proposed works consist of—

1st.—A reservoir formed on the Morna River, by a masonry dam and earthen embankments, east and west of it.

2nd.—An irrigation channel from it, five miles long to the first watershed, and three miles more to the second and third watersheds, from the river, to the east.

3rd.—Filter bed, drinking and bathing basins, with a fountain at the gate of the city of Akola, with pipes to it, $1\frac{1}{2}$ miles long.

Masonry Dam.—625 feet long; extreme height 36 feet; area of section down to 30 feet, $\cdot 3H^2$; below that $21h$, strengthened by counterforts 50 feet apart, centre to centre; wing-walls rising to 8 feet above sill level, and reveting the earthen embankments, which are 8 feet wide at top; slopes 2 to 1, and 3 to 1; area of section $8H + \frac{10}{4}H^2$, length of eastern wing, 2,751, and western wing 9057 feet.

Reservoir.—Extreme length, $2\frac{1}{4}$ miles, extreme breadth, the same: area of water spread, 3,240 acres, of which 1,000 alone are cultivated; and in which there are only three very petty villages.

Content of reservoir:—

Available for perennial irrigation, cubic feet,		...	...	...	41,10,55,831
Available for town supply,	„	...	...	...	5,84,27,360
Waste or standing water,	„	...	...	...	88,43,139
Total content,	„	...	...	...	47,83,26,330

Beside this, there will be available for monsoon irrigation in seasons

of extreme drought at least five times the whole content, from the a perennial flow of the river.

Channel.—Section below ground, 45 square feet; slope 1 in 3,000, discharging 100 cubic feet per second. In first five miles are five masonry superpassages, section 60, discharge 150 cubic feet per second; five road-crossings in the station; two underpassages through embankments in 2-feet pipes, enclosed in masonry culverts, of a slope 1 in 150, discharging 100 cubic feet per second.

In the next three miles are three superpassages and three road crossings, the trenches leading from this main distributary to the fields will be made by the land-owners.

Town Supply —Pipes, 4-inch, sloping 1 in 500, discharge per second ·25 cubic feet. Beds and basins excavated in rock, with walling above ground. Filter bed and bathing basin each 50 feet square, and 15 and 10 feet deep. Drinking basin octagonal, side 40 feet, with a jet in the centre. Ascending filter, through perforated walling and perforated tiles, then large and small pebbles, sand, and magnetic carbide.

	RS
Cost of works, ...	2,65,582
Compensation and road diversion, ...	10,000
Establishment and contingencies, at 20 per cent,	59,116
Total Expenditure, ..	3,34,698

N B.—Labor in Berar is twice as costly as in Upper India and Madras.

Data —Catchment area, 220 square miles; maximum down pour, 12 inches; run off, 6 inches; giving 3,066 millions cubic feet in a year of drought, and filling the reservoir six times.

Flood discharge, (using a local co-efficient of 12 for the formula,) $Q = 12 \times 100 (N)^{\frac{3}{4}} = 67,200$ cubic feet per second; assuming a flood velocity of 13 feet per second, gives a flood section of 5,170 square feet; section allowed is $625 \times 8 = 5000$ square feet; the measured flood sections are in support of this.

Land under water command 45 square miles, all fertile Supply for irrigation during the 8 dry months, 41,00,00,000 cubic feet, or 19 5 cubic feet per second; which at a duty of 200 acres per cubic foot per second will irrigate 3,900 acres.

The supply for monsoon irrigation during the four wet months is more than enough for the whole area under command of 45 square miles;

but taking half, it is 45 — 5 less for waste = 40, and $\frac{40}{2}$ = 20 square miles = 12,800 acres.

This supposes that monsoon irrigation wants a third only of that required otherwise, and taking the area at three times, the water required will be the same in amount as that for the dry season. The channel of supply is however made large enough to supply the whole area under command.

Probable return on this scheme, when in working order :—

3,900 acres, at 7 Rupees, ...	27,300	
12,800 acres, at 2 Rupees, ...	25,600	52,900
Collection, repairs, establishment, 8 per cent., ...		4,232
Nett return on whole capital, 14½ per cent. ...		48,668

Nett return on capital spent on irrigation only, 17 *per cent.*

Rates assumed according to the Baree Doab classification, but at double prices; since the cost of labor in Berar is more than double that on the construction of the Baree Doab canal. Hence for Berar, they are :—

1	Sugar-cane,	12	which are expected to yield mean rates of 7 and 2 Rs., as above, at the least, as there is a strong probability that sugar-cane will be much grown, all the sugar in Berar being now imported.
2	Gardens,	9½	
3	Certain crops,	5	
4	Certain crops,	3	
5	Single watering,	1¼	

L. J.

July, 1871.

No. XXX.

IRRIGATION OF RICE CROPS.

Experiments made at the Shameerpett Tank, in his Highness the Nizam's Dominions, to ascertain the quantity of water required for the Irrigation of Rice Crops. BY MAJOR J. O. MAYNE, R.E. *Superintending Engineer, D. P. W., Hyderabad.*

1. THE Shameerpett tank is situated about nine miles from Bolarum, (14 from Secunderabad,) and early in December last, I visited it in company with the Executive Engineer of the Division, Assistant Engineer, Lieut. Little, to whom the Surveys were entrusted, and Mr. Condasawmy Moodeliar on the part of His Highness's Government. The season selected for commencing work was at the time the cultivation of the second rice crops in the Deccan commences.

2. The tank is one of the fine old specimens found in India. It was constructed about 200 years ago at the same time as the Hoossain Saugor Tank was built, but it has been allowed to fall somewhat into decay; and has not, I understand, been fully utilized in the memory of living man. The collecting basin above it is about 75 square miles. When full the depth of water at bund would be about 40 feet, the area covered by the water would be about 1,375 acres. The depth of water when full over sill of lower sluice would be 35 feet, and the capacity up to 24 feet above our datum amounts to 943,700,000 cubic feet, or 34,951,852 cubic yards, enough to irrigate 3,500 acres at the rate deduced from this experiment. Taking the average rain-fall of 26 inches, and ·8 as co-efficient

of discharge, the possible collection from the whole basin would be 13½ millions of cubic yards, but as there are 32 other tanks of sizes above the Shameerpett Tank, it is probable that the full capacity of the latter would never be utilized. The breadth of bund at top varies from 38 to 50 feet. The outer slope is about 2 to 1. The inner slope faced with coursed stone is generally nearly perpendicular, but in places half to one.

3. - The sluices are of the common native pattern, built on the inner slope of the bund in three stages, all faced with cut stone, with steps leading down to the lowest sluice This arrangement, though no doubt expensive, simplifies the difficulty of dealing with sluices under great heads of water

4. In each stage two circular holes (10″ diameter) are cut vertically and communicate with a common masonry tunnel leading right through the bund. These tunnels are laid in the solid ground one at either end of the bund. The holes are fitted with large beams of wood passing through openings in the platform above, which are raised according to the quantity of water to be discharged. By this arrangement never more than 10 feet head of water has to be dealt with. The timber used is of a wood called khyr or khyer, a species of babool, and weighs about 70 lbs. to the cubic foot. The botanical name is Mimosa Catechu, or Acacia Catechu.

5. These sluices with ever varying heads and discharging the water under such peculiar circumstances rendered it impossible to make any reliable calculations as to daily discharge from tank, and after a few attempts the idea of measuring the water used by this means was abandoned.

6. The irrigation commenced in the last week of November, and the level of the water in the tank at that time was taken as the standard level or datum for our calculations.

7. The plan adopted was very simple. The tank was surveyed accurately, a contour line being run round the level of the water as it stood at the end of November, and other six feet contours were run above that level, in case the water should have risen from any extraordinary causes, such as heavy rain-fall, or bursting of reservoirs on higher level, and also to enable the full capacity of the tank to be calculated.

8. At the same time the water was traced from the tank to the different portions of land under rice cultivation, each of which was accurately surveyed. Originally these were reported by the villagers to be about 100 beegahs, or 75 acres, but they were proved to amount to 280·28 acres.

9. When the irrigation was completed, the tank was surveyed below the datum level, and so the *gross* quantity of water that left the tank could be pretty accurately calculated, and this after all is the important object to ascertain, as wherever reservoirs exist evaporation and soakage always dispose of a large quantity of water; and this tank may, from my experience of several thousands in the Madras Presidency, be taken as an average specimen. The bed of the tank is generally of a rocky nature, so no excess soakage took place.

10. Any heavy rain-falls would have rendered our calculations more difficult, but fortunately from the middle of November to the end of May, the only falls at Secunderabad, which may be accepted for Shameerpett, were :—

Week ending		3rd March	..	..	..	·28
"	"	10th "	..	..	..	·2
"	"	14th April	..	..	..	·7
"	"	21st "	..	..	..	·29
"	"	3rd May	..	..	..	·4
						1·87

so all calculations on that account may be left out without affecting the results in any material degree.

11. When the experiments were commenced, a very petty stream was was found by Lieutenant Little to be running into the tank, but so small that he could with difficulty measure it, and so I have neglected also to notice that.

12. By way of arriving at some conclusions as to the *nett* quantity of water required, we made arrangements for measuring the evaporation from the tank. On this subject I have never before succeeded in arriving at any satisfactory conclusion.

13. I have evaporated water from pans and from pans standing in other pans, but I always felt the results were excessive, and that the evaporation from a large body of water was considerably less than that shown from pans owing to the whole atmosphere immediately over the surface of the tank being moist. On the present occasion I ordered a water-tight tin box to be constructed, and sunk it in a timber raft, so that it might float with its edge slightly above tank water level. The box was then filled to tank water level, and the whole floated out a considerable

distance from the shore, so that the water in the box was placed almost in exactly similar circumstances as the water in the tank.

14. On two occasions careful measurements were taken of the evaporation during the previous fortnight; other attempts were made, but frequently some trifle happened to render the measurements valueless.

15. Between the 12th and 26th January (11 days), the evaporation amounted to 2·12 inches or ·1514 of an inch per diem. Between the 27th January to the 10th February (15 days,) the evaporation amounted to 2·67 of inches, or ·178 of an inch per diem. Mean evaporation ·165 of an inch per diem, and this with the colder weather of December, and the hotter weather of March and April may be taken as a fair mean.

16. The number of days during which irrigation was going on were 185.

The water in the tank fell 11·07 feet.

The results may be summed up as follows:—

Gross quantity of water consumed, ...	2,531,750 cubic yards.
Area irrigated, ...	280 25 acres.

During the period of cultivation no rain fell worthy of notice.

Gross quantity of water consumed per acre 9,042 cubic yards. The crop was, it is understood, an average one.

17. It is worthy of notice that the season not being a very favorable one, the water was husbanded and little or none wasted. Latterly it had to be raised by hand labor, the level of water falling below sill of lowest sluices.

18. The cultivators had complete control over the water.

19. The evaporation represented a depth of water in the tank of 30·5 inches; soakage cannot be determined, but for sake of calculations we may reasonably assume it to be the same as the evaporation, and allowing an average area of water, the loss would have been 1,162,577 cubic yards. This would leave 1,369,173 cubic yards as the approximate nett quantity of water spread over the land, and which over 280·25 acres gives 4,890 cubic yards per acre, and represents a depth of 36·3 inches.

20. These calculations made under exceptionally favorable circumstances, and with great care, agree, I think, somewhat with calculations made in other Provinces. I believe from 7,000 to 10,000 cubic yards of water per acre, in the gross, are generally consumed for rice from tank irrigation and a rain-fall of 36 feet to 40 inches fairly distributed over a

season is, I believe, sufficient to produce an average rice crop, without any artificial irrigation.

21. The survey and measurements were undertaken by Assistant Engineer, Lieutenant Little, under the orders of Lieutenant Cumming, R.E., Executive Engineer, Secunderabad Division, and have, I believe, been made with great care and correctness.

22. The climate here is a dry one, and the general level of the country is about 1,800 feet above sea level. These are points that should be noted in comparing the results with experiments made in other Districts.

23. The total cost of the experiment was very trifling, or about Rs. 300.

J. O. M.

Note on the above Report.

The experiments at this tank, though conducted with great care, are not decisive. With reference to the experiments on evaporation, there is nothing to cavil at; but the following points, which have been neglected in the consideration of the amount of water required for the irrigation of rice, appear to me to seriously affect the value of the conclusions drawn

Firstly.—In para. 10 of his report, Major Mayne, while allowing that any heavy rain-fall would have considerably affected the experiments, proceeds to say that a rain-fall of 1·87 inches during the period of cultivation "may be left out (of the calculations) without affecting the results in any material degree." Surely, if it were not to be considered in any other way, at least 1·87 inches of water, falling on the experimental rice crops, should be added to the actual depth of water expended on the crop; and if we consider besides that the total annual rain-fall is 26 inches, and that on the gathering ground of the tank this gives a possible collection of 134 millions of cubic yards (para 2), it seems rash to neglect 1·87 inches, or one-fourteenth of the annual rain-fall. It is true that this 1·87 inches may not have fallen over the whole gathering ground; but the distribution of the fall should have been ascertained, and the amount of water supplied by it incorporated with the calculations.

Secondly.—"A very petty stream," we are told in para. 11, was at the commencement of the experiments found running into the tank; but Major Mayne has "neglected also to notice that." We are told that the bed of the tank was rocky; we may assume the bed of the water-course

was the same. Under such circumstances, it is frequently a matter of great difficulty to gauge a small stream of water, and, moreover, the amount visible is not necessarily all that passes down the channel. There may have been much more running than was visible to the eye. We are not told whether any investigation of this point was made, and what were the measures adopted for gauging the stream, nor are we informed how long this petty stream ran.

Thirdly.—Why does Major Mayne deduct as much for soakage as for leakage from the gross amount of water expended? The tank is said to have a rocky bed. Moreover, the greater part of such soakage may fairly be charged as water expended in irrigation. If the tank leaks, or if the walls of the tank are of soil admitting the percolation of water, such leakage and percolation must benefit the irrigated lands situated in rear of, and below, the tank bund. Major Mayne deducts nearly 600,000 cubic yards for "soakage." A large part of this, as having percolated into the irrigated lands, should be considered as water expended in irrigation.

To conclude, I think it is a matter for regret that under such "exceptionally favorable circumstances" the experiments, careful so far as they went, were not more thorough. I am convinced had the points I have noticed been considered, the results would have been more in accordance with the hitherto accepted estimates of water required for rice cultivation in other rice-growing countries. In Spain, Portugal, Italy, and other parts of India, Major Mayne's estimates would be considered too little by at least one-half. The only circumstances in favor of the probability of Major Mayne's experiments giving a better "duty" per cubic foot of water than those usually assumed, are that this experimental rice crop was grown in a comparatively cool climate, and at a cool time of the year. The consequence would naturally be that the evaporation, not only in the tank, but in the fields moistened by the waterings from it, would be sensibly diminished, and there would not, therefore, be so frequent a demand for water.

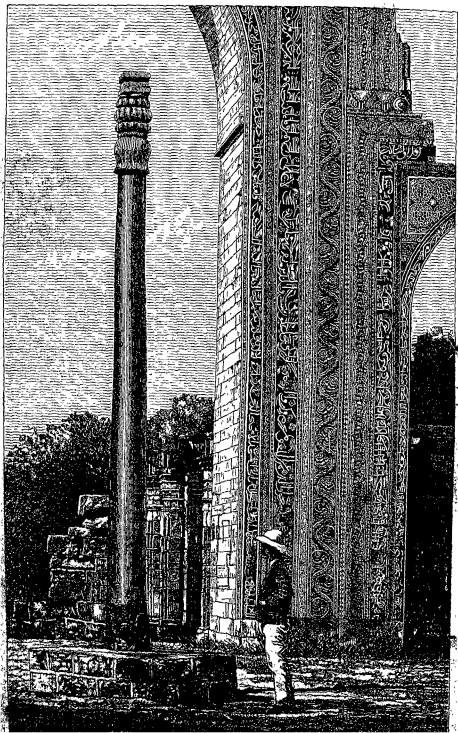
Major Mayne's calculation makes the "duty" of one cubic foot of water per second in rice irrigation, 119 acres,—a result that no country that practises rice irrigation has yet, so far as I know, been able to attain. Seventy-two inches of water would give a rice duty of 60 acres nearly, which is a far more probable duty, judged by N. W. P. experience. In Portugal—I write from recollection, as I have not the information at

hand—the duty with a wasteful mode of irrigation is about 45 acres. Captain Moncrieff, in his work on the irrigation of Southern Europe, says that the rice duty on the Jucar canal in Valencia is locally held to be only 28·3 acres. In Northern Italy, Captain Baird Smith informs us, it is about 40 acres; and finally, Captain Moncrieff, in the work above quoted, says that the duty, *with the aid of the usual rain-fall*, in the Doab, has been as high as 90 acres.

Major Mayne's report is valuable only, therefore, for the actual facts it contains, and these are the rate of evaporation of water in a tank during certain periods, and the quantity of land irrigated from a tank by an amount of water not sufficiently defined.

W. G. R.

PROFESSIONAL PAPERS

ON

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[SECOND SERIES.]

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CAPTAIN A. M LANG, R.E.,

PRINCIPAL, THOMASON C. E. COLLEGE, ROORKEE.

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ERRATA.

No. 3 OF VOL. I. [SECOND SERIES.]

Page 243, line 20, *for* "rearly," *read* "rarely"

" 250, " 33, *for* "he determined," *read* "be determined"

" 260, " 15, *for* "here is," *read* "there is."

" 260, " 21, *for* "feet," *read* feel."

" 263, " 28, *for* "insufficient," *read* "in sufficient"

" 285, " 3, *for* "$m_1 \cos 2\theta$," *read* "$m_2 \cos 2\theta$."

" 285, " 5, *for* "$m_3 \sin 3\theta$," *read* "$m_3 \cos 3\theta$."

" 288, " 15, *for* "Sine $\phi = bop$," *read* "Since $\phi = bop$"

" 290, " 2, *for* "$e\,(k_1' \sin\theta + k_2'' \cos\theta)$," *read* "$e\,(k_1' \sin\theta + k_1'' \cos\theta)$."

" 291, " 18, *for* "simple," *read* "single."

" 292, " 15, *for* "$+ (ab_1^2 + b\,\overline{1+b_1^2})\,Y^2$," *read* "$+ (ab_1'^2 + b\,\overline{1+b_1^2})\,Y^2$."

" 294, " 8, *for* "$= \left\{ a_1 \cos^2\Theta + \frac{a_1' + b_1'}{2} \sin 2\Theta + b_1 \sin^2\Theta. \right\}$"

read "$= R \left\{ a_1 \cos^2\Theta + \frac{a_1' + b_1'}{2} \sin 2\Theta + b_1 \sin^2\Theta \right\}$"

CONTENTS.

No. XXXI.

THE DELHI IRON PILLAR.

[Vide Frontispiece]

ABOUT eight miles to the South of Modern Delhi, and among the ruins of former cities, Hindoo and Mahomedan, which cover an immense area in the neighbourhood of the last of the Indian Mogul Capitals, is still standing an iron monument, erected upwards of one thousand years ago. The accompanying picture of this "Delhi Iron Pillar" has been engraved on wood, in the Roorkee College Press, from a Photograph lately taken by Sergeant Sparke, the College Photographic Instructor. Apart from its historic associations, the pillar has a peculiar interest to the Engineer from the immense size of this sample of iron manufacture, executed by a comparatively rude race in very remote times, and as a specimen of *Indian* Engineering it deserves the special attention of Engineers in this country. In a late number of the "Engineer," very interesting notices and speculations in regard to this and similar masses of forged iron have been published. The following extract from these articles, and from former accounts of the Pillar, (having regard only to its Engineering aspect,) may be appropriately transferred to the pages of "Professional Papers of Indian Engineering."

Mr James Prinsep, F.R.S., *in the Journal of the Asiatic Society, July* 1838;—"The letters of the short inscription on the celebrated Iron pillar at Delhi are well formed and well preserved, notwithstanding the hard knocks which the iron shaft has encountered from the ruthless invaders of successive centuries. The language is Sanscrit. the character is that form of Nágari, which I have assigned to the third or fourth century after Christ, the curves of the letters being merely squared off: perhaps on account of their having been punched upon the surface of the Iron shaft with a short *cheni* of steel, and a hammer; as the absolute engraving of them would have been a work of considerable labor: but this point I

have not the means of determining. The record tells us that a Prince of the name of *Dhava*, erected it in commemoration of his victorious power. Raja Dhava has left behind him at any rate a monument of his skill at forging Iron, for the pillar is a well wrought circular shaft of iron, longer, and nearly as large as the shaft of the *Berenice* Steamer."

GENERAL A. CUNNINGHAM, R E, *in Proceedings of the Archæological Surveyor to Government of India, November* 1863 —"The Iron Pillar of Delhi is one of the most curious monuments of India. Many large works of metal were no doubt made in ancient times, such for instance, as the celebrated Colossus of Rhodes and the gigantic statues of the Buddhists, which are described by Hwen Thsang. But all of these were of brass or of copper, all of them were hollow, and all of them were built up of pieces welded together; whereas the Delhi Pillar is a solid shaft of mixed metal, upwards of 16 inches in diameter, and about 50 feet in length. It is true that there are flaws in many parts, which show that the casting is imperfect; but when we consider the extreme difficulty of manufacturing a pillar of such vast dimensions, our wonder will not be diminished by knowing that the casting of the bar is defective.

"The total height above ground is 22 feet, that of the capital 3½ feet, and that of the rough part near the ground the same. But its depth under ground is considerably greater than its height above ground, as a recent excavation was carried down to 26 feet, without reaching the foundation on which the pillar rests. The whole length of the iron pillar is therefore, upwards of 48 feet, but how much more is not known, although it must be considerable, as the pillar is said not to be loosened by the excavations. I think, therefore, it is highly probable that the whole length is not less than 60 feet The lower diameter of the shaft is 16·4 inches, and the upper diameter is 12·50 inches, the diminution being 0·29 inches per foot. The pillar contains about eighty cubic feet of metal, and weighs upwards of 17 tons"

MR. R. MALLET, *in the "Engineer," dated 15th December*, 1871.—What is the material of the pillar, for upon this depends the nature of the processes by which it must have been made; is it of cast-iron or of wrought-iron? As to this the evidence is as yet not absolutely decisive.

The "Archæological Surveyor," in his report appears to have thought it to be *cast-iron*. What this writer means by *mixed metal* it is hard

to conjecture. Captain BURT, R.E., deemed the pillar to be of *wrought* or forged iron. This latter view receives the following corroborations; the writers accomplished and accurate friend, Mr. James Fergusson, Archt., F.R.S., who has carefully examined the pillar, is clearly of opinion that it is of forged iron. A fragment of it has been recently sent to England, and the writer is informed, on, he believes, good authority, that Dr. Percy has heated and drawn out upon the anvil a portion of it, and considers it to be *forged iron*. This test, probably all that so small a specimen admitted of, is not absolutely conclusive, as Dr. Percy himself would no doubt admit, for some cast irons, especially those made from hematites with charcoal fuel, admit of being heated and at once forged and drawn out hot into a sort of wrought-iron.

There can be seen the mark of the graze of a heavy round shot on one side, at about mid-height of the pillar, and the shaft is apparently slightly cracked across, the widest part of the crack being at the side opposite to the graze mark. The blow, then, was *just not enough* to break completely the pillar by its own inertia, when thus suddenly bent beyond the limit of elasticity. Did we know the *vis viva* of the striking mass, and the density and exact dimensions of the pillar, it would be possible to calculate approximately the cohesion per square inch of the outside film of the shaft at this crack, assuming it really to exist, but wanting such data, and judging by tact or experience only, the writer is of opinion that if of British *cast-iron* the pillar would have been broken completely off by the blow of a heavy shot.

The existence of a doubt as to the material of this pillar, one of the most marvellous metallic monuments in the world—shows with how little completeness it has yet been examined, and how entirely ignorent those who have described this pillar, have been of the importance in elucidating the ancient working of iron in India of an exact metallurgical examination of its material. Let us hope this will forthwith be remedied—by cutting from the pillar (below the surface, it may be) and sending home a piece sufficiently large and long, not only for chemical investigation, but for experimental determination of its extensibility and cohesion per square inch; for physical and chemical examination together, can alone determine with certainty whether it be of oriental *cast-iron* or of wrought, *i. e.*, *forged* iron.

But meanwhile let us take the alternative suppositions, and see to what

they will lead us. At the present day the prevalent belief is probably the correct one, that the production of or working in *cast*-iron is unknown to native Indian workmen south of the Himalaya, and, unless made under European direction, a pig of cast iron of 100 lb. weight could probably not be found in India. Yet how little is systematically known about the matter may be gathered from a recent notice (*Times*, December 4th, 1871) of some remarkable travels in 1868 in Central Asia by a native emissary of the Indian Government. "At Faizabad, the capital of Budukshan, a town a mile and a half in length and a half mile in breadth, along the banks of the Kokcha river, he found the inhabitants skillful in smelting iron, and they send *cast*-iron pots, pans, ornamental lamps, &c., to the market"

Assuming that in past time *cast* iron was known and worked in India, there is yet no reason to suppose that the furnaces in which it was melted could have been much larger than the little cupola furnaces, with blast from native bellows, which are now in use for making wrought-iron direct. The very largest of these native furnaces appear to be those of Burma ("Percy," p. 271, &c.), which by draught only produce about 90 lbs. of iron at each operation. It would have required between 300 and 400 such furnaces, working on casting iron, all got ready to tap and tapped at the same moment, to run a casting of 17 tons—an operation which any practical founder would admit to be impracticable which such apparatus even in the hands of trained European workmen Nor must it be imagined that the product of the existing little Indian cupolas, working on the *direct* process, is ever fluid enough to be *tapped* or run from the furnace. Were it so it might be conceivable that this pillar had been cast, and yet was of a crude wrought-iron, or of a metal intermediate to cast and wrought-iron.

Mr. R. W. Bingham, magistrate at Chynepore, in the Shahabad district of Bengal, in his report on iron making, published in the official descriptive catalogue of the Indian articles exhibited in 1862 at London (4to, Calcutta, 1862), says as to that region of Bengal:— "The metal never runs liquid from the furnace, but falls to the bottom below the blast pipe, from whence it is taken in a flaming mass by a pair of iron tongs, and is hammered on a large stone, or on a rough iron anvil, into a double wedged-shaped pig," &c. This seems to describe the existing process of iron making of the present day, not only in Bengal, but all over British India, differing only in the size of the "bloom" or pig made, which is most com-

monly but 9 or 10 lbs., but in Burmah seems to reach its maximum size, viz., about 90 lbs., or rather less than one-third the weight of "bloom" produced in one operation by the existing Catalan furnaces in Europe, viz., about 140 kilogrammes (" Pelouze and Fremy," vol iii, p. 228).

Are we then to conclude that this pillar was *cast*, in the absence of any evidence in support of that view—indeed, in face of whatever evidence we possess bearing on it—merely because we cannot conceive any other way in which it might have been made in India? If so, this follows, that between the fourth century, A.D., and the present day, the whole art of smelting iron in India has been changed, and that the indirect, or European method has been lost, and with it the knowledge of working in cast-iron itself been also lost. Such a view is untenable, for vessels, or other objects of *ancient cast-iron*, must, in that case, occasionally be found, which does not seem to be the case.

We are thus obliged to consider that this pillar is *not a casting*, but is a huge forging in native Indian or some other Asiatic made *wrought-iron*, and if so, the question arises, how was it forged? We have no evidence that "blooms" of more than 90 or 100 lbs. each, were ever made by Indian methods; these would be too small to build up singly into a bar of 60 inches diameter. It is, however, conceivable that such little "billets" as were procurable from such blooms might be welded up into bars, and these bars made into a faggot, out of which such a bar, by *sufficient means* for bringing it to welded heat, and for then hammering it, might be welded into a cylindrical bar such as that of this iron pillar.

Now, the limit to the size of a faggot that can be welded with given means of *heating it*, is found to be when the mass is so great in proportion to the power of the furnace, that the exterior of the mass, where the heat is being applied oxidates and melts away, owing to the slowness of heating and hence long continuance of exposure to the heat, as fast as piece after piece is laid on to make up for the waste. This limit has been reached before now even in our best reverberatory forge furnaces; it actually was touched upon at Liverpool, in forging the Mersey Company's great 13-inche gun. Unless, therefore, the iron working of India between the third and fourth century, A.D., possessed air furnaces and lofty stalks, or blowing apparatus of some sort upon a scale now unknown, and indeed not conceivable in any form of native apparatus, we may confidently affirm that no faggot to form a welded bar of 16 inches

diameter could have been by any possibility brought to the welding heat at all, or without such waste as to prevent its ever being forged.

If we pass from the heating of such a bar to the forging of it our difficulties are still greater. The limit in size of *hand-forged* work in Europe was about reached in the production in days gone by of the heaviest "best bower" anchor of a ship of the line. The largest section of the anchor shank when welded to the arms was about 8 in. or perhaps 9 in. across, and the welding was effected by the blows of twenty-four "strikers" trained to strike in time, and swinging 14 lbs. to 18 lbs. sledges. The shower of blows dealt for some minutes' spell, upon the mass of iron of this large section produced a very insignificant effect, so that both the faggoting and the welding of such anchors were often very defective, and the strikers having to stand close in a ring, within the short distance for swinging the sledge from the glowing iron, were greatly scorched by its radiated heat, and some with fine skins were unfitted for the work. Hereabouts then, the limit to hand forging was reached, both as to the power of the hand sledge to act upon the mass of iron, and as respected the power of the men to endure the heat radiated from the glowing iron at the short distance from it limited by the length of the handle of a sledge when swinging. Now the section of the shank of a "best bower" of 8 in. or 9 in. diameter is to that of the Delhi iron pillar about as 64 to 201, or the latter would radiate from its heated extremity more than thrice as much heat, and an equal length more than thrice as great a mass to be dealt with by the sledge hammer, as in the case of the anchor. We may, therefore, affirm that even in European hands a bar of wrought-iron of 16 in. diameter could not be welded up by hand labor with the sledge. The latter would produce no adequate impression—least of all in the comparatively feeble hands of Asiatics—and human skin and muscles could not withstand, at 5 or 6 ft. off, the intolerable glare and scorching of such a mass heated to the welding point. How then was this Delhi pillar forged in India, even assuming that some means for heating it existed? Forging by power in some form, of course, suggests itself, but upon what source of power can we even speculate? Human muscles, and the "bullock walk" by which the water skins, are drawn up from the wells or tanks appear the only present sources of power in India. The water-wheel, or *noria*, for *raising* water by the application of such animal power is common, but the production of power by the *descent*

of water on a wheel seems never to have been known in India, where, indeed, except in the hill districts, no "falls" for water power exist. The windmill, though said to have been known in Persia from some very remote period, has never been seen in India, and it need scarcely be said steam-power is out of the question

It is barely imaginable that some form of falling tup hammer raised by men acting on ropes, after the manner of the old ringing engine for pile driving, may have been employed, or some rude form of tup or tilt hammer moved by bullocks acting on a walking wheel; and it is for Indian archæologists to discover if there be any records or traditions of such appliances, without which the methods by which this huge pillar was forged must remain inexplicable. The pillar itself stands before us, so far, a metallurgic enigma; if it stood alone, and were this great ancient forging in wrought-iron alone known to exist in India, we might pass it by, content to suppose it too isolated an instance on which to found any conclusions as to the iron metallurgy of that country in former ages; but, although little noticed, and apparently quite unknown to our European writers on iron metallurgy, this pillar does not stand alone

"Nothing heretofore brought to light in the history of metallurgy seems more striking, to the reason as well as the imagination, than this fact: that from the remote time when Hengist was ruling in Kent, and Cerdic landing to plunder our barbarous ancestors in Sussex, down to that of our third Henry, while all Europe was in the worst darkness and confusion of the Middle Ages—when the largest and best forging producible in Christendom was an axe or a sword blade—these ancient peoples of India, the forerunners of those now so enfeebled and degraded, possessed a great iron manufacture, whose products Europe even half a century ago could not have equalled.

Yet these conclusions rest on no *new* facts, but on the colligation of old ones, by the light of practical knowledge Indian archæologists and writers have long known of the existence of these iron monuments of an ancient and lost art in India, but their importance has, the writer believes, not before been recognised as bearing on ancient oriental metallurgy. The reason of this is that those who have examined the monuments of India, however scholarly and able in many ways, have not been metallurgists, and have had no practical knowledge of iron working. The ancient, and, indeed, the existing technology at large of India—still more

of Asia at large—remains almost unexplored and undescribed, and whenever it shall be examined, analysed, and described by really competent men—and such have never yet been commissioned with the task—results even more strange, and perhaps of more importance, historical and practical, than these deducible from the Delhi iron pillar, will, no doubt come to light.

Mr. George M Fraser, *in the Engineer, dated* 12*th January*, 1872.—Mr. Mallet's article in the Engineer of the 15th ultimo, on the very singular iron column within the mosque of the Kutab, near Delhi, is one which cannot fail to be particularly interesting to all students of the history of iron metallurgy, and is certainly in great measure exhaustive and complete. Mr. Mallet, however, whilst coming to the conclusion that this monument is of malleable metal, seems yet inclined to suggest the possibility that at some distant date the iron workers of India may have had a knowledge of iron in its liquid form which at present they do not seem to possess, and of which knowledge history affords us no record. Mr. Mallet's great difficulty—and at first sight there can be no question that it is apparently an insurmountable one—is that—assuming the column to be of wrought-iron—of forging such a mass of metal at a welding heat by the mere manual power within reach of Indian iron workers at the supposed date of "its manufacture" The experience of many years spent in charge of an iron works in Southern India, where cast-iron was produced by the European method, but which experience also comprised constant intercourse with the native smiths of the country and a knowledge of the material they used, and of the method of its production and capabilities in manufacture, may perhaps entitle the present writer to offer what he ventures to believe will be considered by practical men a satisfactory explanation of how such material, labor, and capabilities might have been used to produce the column now under notice.

In the first place, then, the writer would record his decided opinion that the column of the Kutab is of wrought, or at all events of malleable iron, for during the whole course of his Indian experience, which included many visits to the native smelting furnaces in the Salem and Malabar Collectorates, together with the constant practice at his own works in the production of *edged*, not *chipping* tools, of the native steel; he never found anything approaching an attempt to *tap* one of these fur-

naces, nor heard any Indian workman speak of cast-iron but as of a material utterly useless to him, and beyond his ken.

The process of smelting, as pursued in Southern India, is probably sufficiently well known not to require any further description here, than, that in a perpendicular circular furnace about 6 or 8 feet in height, and of a diameter at its greatest width of about 18 inches—the blast to which is supplied by the alternate inflation and compression of four or six goat skins worked by hand, as in the ordinary smiths' fires of the country—the black magnetic oxide so common in the laterite formation is converted not into cast-iron, but rather into a mass somewhat similar to the loup of the Catalan forges, presenting in parts a crystalline, and in others a fibrous, fracture The removal of these lumps or loups—mootees they are called by the natives of Malabar—necessitates the breaking open of the whole of that part of the little furnace which corresponds to the timp and fore hearth of an English blast furnace, and in order to prepare for this the charging at the top is stopped, as is also the blast, and the whole contents allowed gradually, as combustion exhausts itself, to sink down into the hearth, whence, when cool, it is removed. These loups or mootees (the writer must object to Mr. Mallet's term "pig," as applied either to these or any result of the cementation process, as the term certainly conveys, to English ears at least, the idea of cast iron) are generally from 80 to 112 lbs in weight, and it is from the building up of lumps of metal, such as these, one upon the other, with such reheating and hammering as may have been found necessary to effect cohesion, that the writer conceives the Kutab column to have been produced.

He cannot think that there is anything impossible in such a mode of proceeding, nor anything in the actual working of the material—which is of a most malleable nature, and weldable at a very low comparative heat—which the native smiths are unequal to performing. Fifteen inches diameter is certainly a very, very large bar; but it should be recollected that in the process just suggested it would only be the surface of each successive mootee (previously, of course, heated and hammered to the proper section) which would require to be at welding temperature, and that such a temperature for such surfaces might readily be produced in good charcoal fires without much injury to the iron so treated. The writer has himself seen shafting of between 6 and 8 ins. diameter heated in open fires composed of charcoal and "bratties" (sun-dried cow-dung),

and welded to good joints by native smiths in the Madras Presidency. Conceiving, then, that the column may have been thus built up—and of course the supposition is directly opposite to the idea that it might have been composed of longitudinal bars welded together—we find the capital left to be accounted for, and the very form of this, is one which could readily have been produced by swaging, and finishing with such chipping (but this only to a small extent, the writer believes), as may have been found necessary. It is also to be recollected that the column itself has never, save, of course, in the act of raising it, been submitted to any severe strain, and that its cohesion has never in anyway been tried in tension, as is ordinary shafting. Further, the extraordinary amount of quiet perseverance with which the natives of India are endowed, and the illimitable amount of mere manual labour which any great Eastern ruler could bring to bear upon such an object of ambition as the construction of a trophy or monument as this column may be considered, would also go to help us to the conclusion that this huge rod of iron may have been manufactured in such manner, and with such material and appliances as the writer has described. Again, it may be remarked that, even supposing other similar columns to exist, as Mr. Mallet seems to think, yet even this very existence, in so confessedly small a number, proves them to have been quite exceptional productions, and not in any way portions of a systematic manufacture of large iron forgings It is, too, a point well worthy of notice that there would seem to be no examples left of what might be described as the intermediate stages of iron-working *id est*, examples of forgings which, whilst exceeding greatly in size and weight the present ordinary productions of the Indian iron smiths, would yet be of far smaller dimensions in every way than this column of the Kutab. The writer is, therefore, forced to the conclusion that this, and also any similar Indian columns, must be regarded as purely exceptional productions—types of no manufacture ever extensively or usefully existing in India, and indicating neither the possession of machinery calculated to produce such types in any number, nor even much smaller forgings Exceptional, however, as they appear to be in every way, he yet ventures to believe he has pointed out the process by which in all probability, they were manufactured; and if they can be regarded but as mere monuments of some now nameless ambition, they are yet wonderful examples of that ant-like perseverance and patient industry which in many ways mark the metal workers of India.

P S.—May not the words "mixed metal" mean mixture apparently of wrought and cast-iron, which is clearly the characteristic of the crystalline and fibrous fracture of the native loups or mooties; and has the great depth, and consequent weight of the column under ground, been used as a counterpoise in raising it into a perpendicular position?

GENERAL A. CUNNINGHAM, R.E., *in a note furnished to the Editor, March* 1872:—When I wrote the preceding account in 1863, I described the Iron Pillar as formed of "mixed metal" This I did on the authority of the late Mr. Frederick Cooper, Deputy Commissioner of Delhi. He was then preparing a hand-book for Delhi, in which I find the pillar is thus described.—"The celebrated *Loha-ka-lát*, or iron pillar, which is however a misnomer, for it is a compound metal resembling bronze." On thinking o[illegible] this question some months afterwards, it struck me that a *bronze* [illegible] [illegible]uld never have escaped the rapacity of the Mahommedan con-[illegible] therefore obtained a small bit from the rough lower part of [illegible] I submitted to Dr. Murray Thomson,* who kindly fur-[illegible] with the result of his analysis, that it was "pure malleable iron of 7·66 specific gravity." I have since referred to various books to see what account was given of the Pillar by different tourists, and I find that the opinion that the pillar was made of mixed metal or bronze has certainly prevailed since the beginning of the century. But it is certainly of much older date, as the notorious Tom Coryat, more than two hundred years ago, speaks of the *brazen* pillar which he had seen at "*Delee.*"

An equally important error has prevailed regarding the depth of the portion of the pillar under ground, which was generally believed to be at least equal to its height above ground, but an excavation made by my assistant, Mr. J. D. Beglar in 1871, showed that the Iron Pillar terminated about 3 feet below the present ground level, in a knob like a flat turnip. To this knob were fixed eight short thick bars of iron, on which it rested, and these were secured to stone blocks by lead. My assistant passed a bamboo right underneath the pillar.

I may add that the letters of the principal inscription of Raja Dhava, were originally filled with silver, small bits of which metal may still be seen clinging to the angles of the letters.

* Professor of Experimental Science at the Thomason C E. College, Roorkee, and Chemical Analyst to the Government of the N. W. Provinces.

No. XXXII.

TOOLSEE WATER SUPPLY PROJECT.

[*Vide* Plates XXIV., XXV., XXVI and XXVII.]

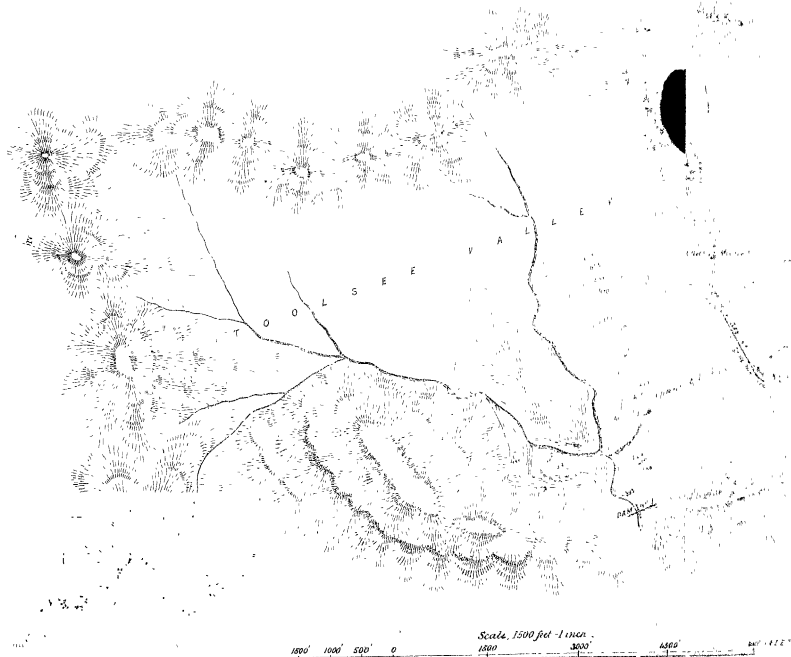
BY RIENZI G. WALTON, C.E., *Acting Executive Municipal Engin*[illegible]
Bombay.

IN order to arrive at a correct result as to the value o[illegible] scheme as an auxiliary supply to Vehar, I have endeavored to ascertain as far as possible the average quantity of water that has been annually collected in the Vehar Lake and what has been the average quantity annually drawn from it, the close proximity of Vehar to Toolsee being, I think, a sufficient justification for adopting the same data in both cases

In order to ascertain the average annual supply of water to the Vehar Lake (say in 1862) it is necessary to take the following into consideration, that—

On the 7th of June, 1862, when the Lake first commenced to rise, the readings on the gauge showed the surface of the Lake to be 48′ 1″, *i. e.*, 11′ 1″ below the top of the waste weir, or 79 59 above Puspolee datum (90·67 − 11·08). At the end of the monsoon, and on the 6th October, 1862, when the surface of the Lake first began to fall, the readings on the gauge showed the level to be 57′ 6″ or 1′ 8″ below the top of the waste weir (89·01 above Puspolee datum).

The capacity of the Lake between the levels 89·01 and 79·59 is 8,053,000,000 gallons nearly, *i.e.*, the quantity of water by which the Lake was shown by the gauge to have increased from the 7th June to

TOOLSEE PROJECT.
CONTOURED PLAN OF THE TOOLSEE RESERVOIR.
T O O L S E E V A L L E Y
Scale, 1500 feet -1 inch.
1500' 1000' 500' 0 1500 3000' 4500'

11th October was 3,053,000,000 gallons; but in order to ascertain the whole amount of addition to the Lake during those dates it is necessary to take into consideration the daily supply to Bombay *plus* the evaporation during the monsoon

Now assuming the daily supply to be 11,500,000 gallons, the total supply from 7th of June to the 11th of October will be 11,500,000 gallons × 127* days = 1,429,000,000 gallons.

To this should be added 168,000,000 gallons due to evaporation during the monsoon; then the total addition to the Lake during the monsoon will be—

1,429,000,000 + 3,053,000,000 + 168,000,000 = 4,650,000,000 gallons.

From the readings of the gauge it has been calculated that the following quantities have been collected each year :—

Year	Gallons	Year	Gallons
1862	3,053,000,000	1867	[illegible],653,000,000
1863	3,522,000,000	1868	[illegible]17,000,000
1864	2,419,000,000	1869	4,180,000,000
1865	4,126,000,000	1870	3,021,000,000
1866	4,112,000,000		

Showing a total of 31,332,000,000 gallons for 9 years, or an average of 3,481,000,000 gallons per year as remaining in the Reservoir at the expiration of the monsoon.

From this result (according to Mr. Ormiston's calculations) 2 feet should be deducted as due to evaporation during the fair-weather season. This will reduce that quantity to 2,852,000,000 gallons (3,481,000,000 − 629,000,000),

* This number (127) represents the number of days between these dates on which the gauge showed either a continual increase, or not the usual rate of depression of the level of the Lake, that is to say, the number of days on which the gauge showed a rise in the level of the Lake, and the number of days on which the depression of the gauge has not shown a "draw-off" as much as the estimated daily consumption.

It has been arrived at as follows —

From the table for the year 1862, it is evident that between the 2nd of August and the 4th of October, the level of the Lake constantly rose, and therefore that between those dates an addition was made to the level of the Lake sufficient to cause it to rise notwithstanding the daily "draw-off."

Therefore the daily supply multiplied by the number of days between these dates must be added to the above quantity 3,053,000,000 gallons.

Again, the level of the Lake on the 21st of June was 49·5 on the gauge—and on 28th 49·4, showing a depression of 1-10th foot only for that week. Now as it has been ascertained that when the surface of the Lake is at this level the usual weekly rate of depression is 4-10ths, it is fair to assume that either the supply to Bombay had been reduced, or that the rainfall had been sufficient to furnish ¾ of the week's demand, as we know that the supply had not been reduced, it follows that 5½ times the daily supply of water was collected in the Lake during those seven days. By this method it will be found that for the year 1862, 127 days supply + the evaporation for that period must be added to the above quantity 3,053,000,000 in order to obtain the total quantity of water collected in the Lake during that monsoon.

The following table has been worked out in accordance with the method explained in the foot-note, page 321 .—

	Days.		Days.
1862	127	1867	126
1863	118	1868	110
1864	98	1869	126
1865	122	1870	112
1866	84		

a total of 1,032 days for 9 years, or an average of 115 days per year.

I have shown that during the fair-weather portion of the year the total consumption has been 2,852 million gallons, and as we have ascertained that the average monsoon consists of 115 days, it is perfectly clear that the daily consumption must be $\frac{2,852,000,000}{365-115}$, or 11,500,000 gallons nearly per diem.*

Having ascertained this fact, I now proceed to obtain the average total quantity drawn off during each monsoon, thus :--

Year	No of Days of Rain		Daily Consumption		Million Gallons.
1862	127	×	$11\frac{1}{2}$	=	1,461
1863	118	×	$11\frac{1}{2}$	=	1,357
1864	90	×	$11\frac{1}{2}$	=	1 137
1865	122	×	$11\frac{1}{2}$	=	1,403
1866	62	×	$11\frac{1}{2}$	=	966
1867	123	×	$11\frac{1}{2}$	=	1,449
1868	114	×	$11\frac{1}{4}$	=	1,369
1869	109	×	$11\frac{1}{2}$	=	1,449
1870	105	×	$11\frac{1}{2}$	=	1,281
Total, ...					11,869

To this amount should be added the quantity due to evaporation, and

* *Another method for ascertaining the daily "Draw-off" has been worked out as follows* .—
The capacity included between the levels recorded from the expiration of one monsoon to the commencement of the next (deducting for evaporation) divided by the number of days between these dates (allowances being made for slight addition to the Lake—after the surface has once commenced to decline) gives the following quantities as the daily "Draw-off" for each year —

Year	Daily Draw-off
1862	10,300,000
1863	11,600,000
1864	12,300,000
1865	10,700,000
1866	11,600,000
1867	12,100,000
1868	11,700,000
1869	12,100,000
1870	11,800,000
Total, ...	104,200,000

which equals $11\frac{1}{2}$ million gallons per day—a result similar to that shown by the other method.

taking this at 168 million gallons per monsoon, the total quantity drawn off during the above nine years will be—

Gallons		Gallons		Gallons
11,869,000,000	+	168,000,000 × 9	=	13,381,000,000

I have shown above that the quantity collected in the Lake as indicated by the gauge during 9 years is 31,332,000,000 gallons.

Therefore the total quantity of water collected in the Reservoir from the year 1862 to 1870 is—

31,332,000,000 + 13,381,000,000 = 44,713,000,000 gallons.

or an average annual addition to the Lake of 4,968,000,000 gallons

On the 7th June, 1871, the surface of the Lake fell to 46′ 4″ on the gauge, *i. e.*, 1′ 9″ lower than the level of Lake in 1862, and consequently we had up to that date drawn to a small extent (about 5 weeks' supply) on the storage of Vehar in addition to what we received from the annual rainfall.

This fact alone affords sufficient evidence of the insufficiency of the Vehar Lake, and its inability to remain the sole source of supply to Bombay.

Observed data show the average height of the Lake at the immediate expiration of the monsoon to be 1′ 8″ below the top of the waste weir; it is therefore evident that any addition to the gathering-ground of Vehar could (in most years) only contribute a quantity of water equal to the capacity of the Lake between the level of the top of the waste weir and 1′ 8″ below it.

I have already shown that the average yearly supply for the last 9 years from 7th June 1862 to 7th June 1870 has been 4,968,000,000 gallons. From this quantity however (in accordance with the result of Mr. Ormiston's calculations) I deduct 2′ 6″ in depth, or about 797,000,000 gallons as the yearly evaporation, thus leaving 4,171,000,000 gallons as the quantity available annually for distribution, &c., or 11,500,000 gallons per day.

For a population of 850,000 this supply will give 13·5 gallons per head per diem, but as Mr. Ormiston's calculations show only 12 gallons per head per diem, it is clear that $\frac{1}{9}$ of the whole quantity available is lost by leakage through the dams, strata, or along the pipe line.

From the above the following information is gathered; that—

The average annual addition to the Lake is 4,968,000,000 gallons.

The annual demand is 4,215,000,000 gallons

The rate per head per diem is 12 gallons.

The amount wasted unaccountably is 1·5 gallons per head per diem

Before proceeding to apply the above results to the Toolsee reservoir, I here propose to investigate what our present and future position will be with reference to the water-supply from Vehar under the most unfavorable circumstances, say partial failures of rainfall for the years 1872 and 1873

On the 20th May, 1871, the surface of the Lake was at 47′ 2″ on the gauge (78 67 above Puspolee datum).

The rain contributed about 100 days' supply to the Lake besides that which remained in the Reservoir after the rain ceased.

At the end of the monsoon the surface of the Lake was at 48′ 4″ on the gauge, or 79′ 84″ above Puspolee datum. Between 78·69 and 79 84 there is a capacity in the Lake of 760,000,000 gallons.

During the 100 days' rain about 1,159 million gallons left the Lake, also about 80 million gallons were lost by evaporation, &c ; the total quantity therefore collected in the Lake during the monsoon of 1871 was

$$760,000,000 + 115,900,000 + 80,000,000$$
$$= 2,000,000,000 \text{ gallons only.}$$

As shown above, the average quantity of water collected in the Lake during an ordinary monsoon is 4,968,000,000 gallons. We have therefore this year collected only 0 4 of that quantity.

I will now go on to see what will be the quantity of water in all probability left in the Reservoir by the 7th of June, 1872 (about the time the monsoon usually commences)

On the 16th September, 1871, the surface of the Lake was at 79 84 on Puspolee datum.

From the 16th September to the 7th June we shall have drawn off at the present rate,

		Gallons.
		261 × 109,000,000
		= 2,878,000,000
Add for evaporation	...	466,000,000
Total	......	3,344,000,000

which will be the quantity required up to 7th June 1872.

Now between 79·84 and 66·4 the capacity of the Lake is—

3,311,000,000 gallons,

so that on the 7th June, 1872, the surface of the Lake will be at 66·4 on Puspolee datum, *i e*, 34′ 4″ on the gauge.

We shall then have on the 7th June 1872, about the time that the monsoon may be expected to commence, a quantity of water in the Reservoir contained between 66 4 and 31 67 on Puspolee datum, *i. e.*, about 3,974,000,000 gallons. Now suppose the monsoon of 1872 to be a failure, and that we collect the same quantity of water only as was received into the Lake in 1871, that is, 760,000,000 gallons, we shall then have remaining in the Reservoir at the end of the monsoon of 1872—3,974,000,000 + 760,000,000 = 4,734,000,000 gallons.

The surface of the Lake will then be at about 70 16 on Puspolee datum, or 38′ 8′ on the gauge; of this we shall require (as in 1871-72) 2,878, 000,000 gallons for use up to 7th June, 1873, before the monsoon of that year commences, and also about 425,000,000 for evaporation, making a total of 3,303,000,000.

We have (as before stated) 4,734,000,000 gallons in the Reservoir; we shall therefore have remaining in the Lake under the above conditions on the 7th June, 1873, 1,431,000,000 only, and its surface will be at 50·27 on datum, or 18′ 9″ on the gauge.

From the foregoing it will be plain to all that we shall have plenty of water in the Reservoir up to the monsoon of 1873, and even if the monsoon of 1872 gives us not more than half the quantity collected in 1871. But in this case, however, the surface of the Lake would be about 42 5 on datum, or 11′ 0″ on the gauge, and we should have only 500,000,000 gallons remaining.

Whether it would be injurious to health to use water for domestic purposes drawn from so low a level as this, is a question which I leave to chemists and the medical profession to decide.

Now I have pointed out that the quantity in the Lake at the commencement of the monsoon (7th June, 1873), will be 1,431,000,000 gallons, let us assume a still further failure of rain for 1873, although I must confess I consider the probability of three successive failures in the monsoon as exceedingly remote.

However, starting from the 7th June, 1873, with the quantity of water in the Lake available at 1,431,000,000 gallons, we should get from the partial monsoon, as in the preceding years, say 760,000,000 gallons; the

total quantity therefore at the end of that monsoon would be 2,191,000,000 gallons.

We should require for use up to the 7th June 1874, 2,878,000,000 gallons, and also about 250,000,000 gallons for evaporation during that time; the total supply required would then be.

$$2,878,000,000 + 250,000,000 = 3,128,000,000, \text{ gallons.}$$

We should therefore, after having drawn off all the water available from the Lake, still be deficient of the quantity required by about 937,000,000 gallons, which, taken at 10,900,000 gallons per diem, represents a supply of 86 days.

If the monsoon commenced later than the 7th June, we should, of course, be deficient in our supply by a greater number of days.

This, then is our position as regards the supply from the Vehar Lake if we had three successive partial failures of the monsoon.

If, however, we were to have a nearly total failure in 1872, and a partial one in 1873, we should then be about 240 days short of supply up to 7th June, 1874.

Taking a case of two total failures, we require about 4,900,000,000 gallons each year, and allowing less for evaporation as the Lake falls, the demand for two years will be, say 9,300,000,000 gallons; leaving about 1,500,000,000 gallons only in the Reservoir; this would reduce the surface of the Lake to 19′ 6″ on the gauge or 51·00 on datum.

Let us now see how we can best make use of Toolsee gathering-ground and storage as an auxiliary to Vehar.

I have shown above that the total quantity of water collected in Vehar Lake from an average monsoon is 4,866,000,000 gallons.

The area of the Vehar Lake is taken at 1,140 acres, and of the gathering-ground at 2,800 acres

Let us take the average rain-fall at 102 inches, and let x be the proportion af rain fall collected in the reservoir from the gathering-ground.

Then 8·5 × area of the Lake in feet + 8 5 × area of the gathering ground in feet,

$$= \text{quantity of water collected in the Reservoir.}$$

Substituting values we have $8 5 \times 1,140 \times 43,560 + (8{\cdot}5 \times 28,000 \times 43,560)\, x$,

$$= \frac{4968,000,000}{6 25}$$

$$\therefore x = \frac{795,000,000 - 422,000,000}{1,036,728,000}$$

$$= \frac{356,168,600}{103,672,800} x = 0.36$$

Now, if we take the above value of x, viz., 36 for Toolsee and deduct therefrom (according to Mr. Ormiston) 2·6 for the yearly evaporation from the Reservoir, and take the area of the Toolsee Lake at 250 acre (the top of the Dam being, at 450·00) we have—

$$6.25 (8.5 \times 250 \times 43,560 + 36 \times 8.5 \times 1,197 \times 43,560)$$
$$= 1,575,733,993 \text{ gallons.}$$

Deducting for evaporation

$$6.25 (2.5 \times 246 \times 43,560) = 167,433,750$$

Total......1,408,000,000 nearly

That is, the quantity of water collected in the Reservoir at Toolsee for yearly use is nearly 1,408,000,000 gallons, or 3,857,000 gallons daily, $\frac{1}{9}$th of which will be lost as at Vehar, leaving for daily delivery 3,430,000 gallons, equivalent to 4 gallons per head per diem for a population of 850,000.

The above being the result of a rainfall of 102″, let us now take the case of a smaller fall of rain, say, 84″.

Taking the same conditions as before, we have—

$$7 \times 1,140 \times 43,560 + x (7 \times 2,800 \times 43,560)$$
$$= 795,000,000$$
$$\therefore x = \frac{795,000,000 - 347,608,800}{853,776,000} = .52.$$

This value of x is more likely to be correct than the former one.

Taking this last value of x for Toolsee

We now get—

$(7 \times 250 \times 43,560 + .52 \times 7 \times 1,197 \times 43,560)\ 6.25 = 1,675,152,52$ gallons.

and deducting for evaporation

$$(2.5 \times 246 \times 43,560)\ 6.25 = 167,433,750$$

Total = 1,507,718,775

The quantity of water collected and available for use for one year at Toolsee is therefore about—

1,508,000,000 gallons,

or 4,130,000 gallons per diem.

$\frac{1}{9}$th of which will be lost (as at Vehar) leaving 3,670,000 as the daily

supply, or about $4\frac{1}{4}$ gallons per head per diem for a population of 850,000.

Referring to our Diagrams of height of water in dam, we see that after every third year the Vehar Lake has overflowed. It is, therefore, only during those years in which the surface of the Lake is below the top of the waste weir that any addition could be made to it from Toolsee

The years on which the Lake has not overflowed, the average level of the surface has been 1′ 8″ below the waste weir. Now the capacity of the Lake down to this depth is about 565,000,000 gallons. This quantity therefore could have been usually brought into Vehar, and would have increased the quantity stored in that Lake by 1 75 gallons per head.

It is evident then that for the greater number of years the Vehar Lake has been in existence, the annual addition that could have been rendered to it from utilizing the Toolsee gathering-ground would have been about 565,000,000 gallons, unless the dams and waste weir at Vehar were raised.—an alternative not likely to be advocated by any Engineer familiar with their present state.

Let us now see what our position would have been if we had the power of so utilizing the rainfall on the Toolsee gathering-ground so as to raise the level of the Vehar Lake to the top of the waste weir at the expiration of each monsoon.

The Lake overflowed in 1869. During that year, therefore, none of the water from Toolsee could have been used

At the end of the monsoon 1870 the surface of the Lake was 1′ 7″ below the top of the waste weir; we could therefore during that monsoon have received an addition from Toolsee to the extent of about 537,000,000 gallons.

In 1871 we collected in Vehar ·40 only of the average annual quantity; and assuming the same proportion to have been collected at Toolsee we should have

$$1,402,000 \times \cdot 40 = 574,000,000 \text{ gallons}$$

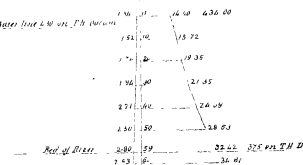
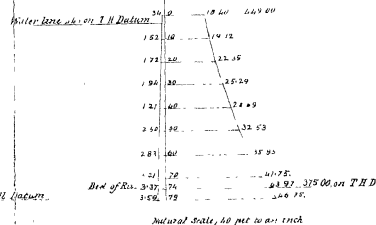
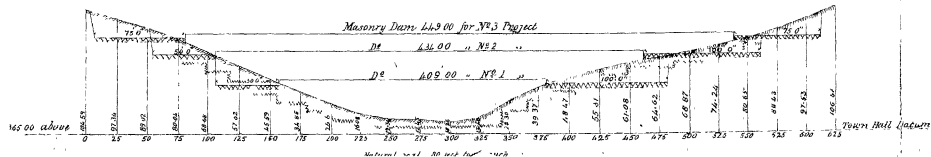
which could have been directed into Vehar. We should have thus brought in during the years 1870-1871—

$$574,000,000 + 537,000,000 = 1,111,000,000 \text{ gallons.}$$

If in 1872 and 1873 there are again partial failures in the rainfall, we shall be able to bring into Vehar from Toolsee—

$$2 \times 574,000,000 = 1,148,000,000,$$

a total for 4 years of 2,259,000,000 gallons.

TOOLSEE VALLEY.
PLAN AND SECTIONS OF No 1 DAM.
CROSS SECTION OF MASONRY DAM FOR No 1 PROJECT.
Bed of River
CROSS SECTION OF MASONRY DAM FOR No 2 PROJECT.
Bed of River
375 on T H D
CROSS SECTION OF MASONRY DAM FOR No 3 PROJECT.
Water line 449 on T H Datum
Bed of Riv.
375 00 on T H D
Natural Scale, 40 feet to an inch
LONGITUDINAL SECTION OF DAM LINE FOR ALL PROJECTS.
Masonry Dam 449 00 for No 3 Project
Do 434 00 " No 2 "
Do 409 00 " No 1 "
365 00 above
Town Hall Datum

We have seen above that in the case of partial failures of the monsoon in 1872 and 1873 we should be deficient by 937,000,000 in Vehar up to 7th June, 1874, after all the water available by the outlet had been drawn off, and I have also shown that if the Toolsee gathering-ground had always been utilized we should have added 2,250,000,000 gallons since 1870 : by this means the effect of three partial failures of the monsoon at Vehar would have been counterbalanced.

If, however, in 1872 there were a total failure and in 1873 a partial one, we should then only have been assisted by Toolsee to the extent of of 1,685,000,000 gallons, and our deficiency at Vehar would have been 2,600,000,000 still leaving a deficiency at Vehar up to 7th June, 1874 of 915,000,000 gallons. This quantity should, I think, form the basis upon which any auxiliary supply to Vehar should be judged. For from the above figures it is clear that if a storage ground had been constructed at Toolsee with a capacity equal to 915,000,000 gallons or more, and whose rainfall (after that quantity had been stored) would discharge itself into Vehar, no chance of a water famine would have existed even under the most unfavorable conditions on which I have framed my calculations.

I have worked out three Projects with reference to Toolsee.

The first is known as one of Mr. Russel Aitken's schemes, and is thus described by him at page 16 of his Report on the extension of the Bombay Water Works :—

"The second plan (Scheme No. 3) for obtaining water from Salsette, which I have now to propose, is the construction of a Dam in the river Tassoo just below the village of Toolsee, whereby the waters of the upper portion of the river will be diverted into the Vehar Lake, which would thus have its gathering-ground increased by 1,600 acres, so that the present supply from Vehar might be increased from 5 to $6\frac{1}{4}$ gallons."

For this scheme Mr. Aitken claims a return into Vehar of from 5 to $6\frac{1}{4}$ gallons, but, according to the calculations I have given at a former part of this Report, I think $4\frac{1}{4}$ gallons per head is all that can be excepted as the average annual collection from the Toolsee gathering-ground.

It must be remembered that although Mr. Aitken's Dam would undoubtedly enable the whole of the rain-fall on the Toolsee gathering-ground to be diverted into Vehar, yet unless the level of that Lake was sufficiently low to admit of a capacity equal to this addition, a considerable

portion of it would simply pass over the Vehar waste weir, or might be allowed to escape by some other process.

Mr Aitken goes into very little detail of this scheme, and I am not surprised at his reticence, since he was satisfied, as all others must be who have gone into the subject, that an independent and not an auxiliary supply is what is required to give an efficient water-supply to Bombay Toolsee at the best can only be an auxiliary.

I have before pointed out that for the greater number of years the Vehar Lake has been in existence the level of that Lake has been, at the expiration of the monsoon, at or about the level of 1′ 7″ below the top of the waste weir, and that this capacity represents 5,65,000,000 gallons.

Now taking the total rainfall of Toolsee to be 1,508,000,000, the difference between 1,508,000,000 and 565,000,000 = 943,000,000, will show the quantity which would have passed over the Vehar waste weir for the greater number of years that the Lake has been in use.

Mr. Aitken's estimate for this work is Rs. 2,01,060, which amount in consequence of the fall in the rates for materials and labor, and by the substitution of chunam for cement in the Dam, I have been able to reduce to Rs. 1,38, 315.

A waste weir and a regulating sluice I have provided for in this scheme in order not to render it compulsory, when the Vehar Lake is full, that the surplus water from Toolsee should pass over the Vehar waste weir.

By Project No. 2 it is proposed to impound the water on the Toolsee ground by a Dam at such a level as to utilize the ridge of hills between Vehar and Toolsee as a waste weir, that is to say, to erect a Dam 64 feet high above the bed of the Tassoo river, and by so doing to conduct the surplus water (after the Lake had filled to this level 430·00) over the dividing ridge of hills between Toolsee and Vehar into the latter.

I estimate the quantity of water impounded by such a Dam to be 581,000,000 gallons, the whole of which can be drawn off into Vehar at any time that it may be required by means of a channel (partly in cutting and partly in tunnel) governed by a Penstock.

The top of the Dam will be 434·00 above Town Hall datum, and that of its waste weir (150 feet in length) 431·25.

When the water in the Reservoir rises to 430·00 all additional rainfall will flow over the low dividing ridge (already alluded to) into Vehár. In

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TOOLSEE PROJECT.
PLAN AND SECTION OF DIVIDING RIDGE BETWEEN TOOLSEE AND VEHAR.
SECTION ON A B.
Top of Dam 448 on Datum
Water level 445.00
Surface of Ground
427.04
Scale
HORIZONTAL
VERTICAL
1000 FEET
Top of Dam for No 3 Project 448.50 on Town Hall Datum
High water level 445.00
Tunnel
SECTION OF WASTE WEIR AND STANDARD.
Top of Waste Weir 445 on D
Surface of Ground
Scale 8 feet = 1 inch
on T.H.D.

the event of the Vehar Lake being full, and to prevent the flow of the Toolsee water over the Vehar waste weir, I propose to raise the level of this dividing ridge to 131 25 temporarily by means of cast-iron standards and boarding, so that, as soon as the surface of the Lake is raised to that level, the surplus water, instead of being discharged over Vehar waste weir, will pass over the one at the Toolsee Dam.

The result of this scheme will therefore give 581,000,000 gallons, or 1 9 gallons per head per diem for the present population, stored and available at all times as an auxiliary to Vehar, and also as much of the available Toolsee rainfall as can be annually stored in the Vehar Lake.

The total estimated cost of this scheme, less compensation for ground, is Rs. 1,75,221.

Project No. 3 differs from No. 2 only in having higher Dams, and consequently increased storage.

The Dam (of rubble masonry) will be 74 feet high, *i.e*, its top will be 449·00 on datum (Town Hall) with a waste weir (150 feet long) 446 25 on datum.

The level of the low ridge of hills separating Vehar from Toolsee being 430 00 only, it becomes necessary to erect a small Dam upon its crest, the level of the top of which will be 448 5 on datum : this Dam will be furnished with a waste weir 200 feet long, the level of which will be 445 00 on datum.

The greatest depth of this Dam will be only 21 0 feet, a fact which will entirely do away with the cause of fear which has hitherto obtained at the construction of Dams on the water-shed of the Vehar Lake.

By this scheme I estimate 1,451,000,000 gallons of water will be stored up available at any time, not only as an addition to Vehar, but would afford 365 days' supply of 4½ gallons per head per diem of the present population, should the Vehar supply at any time become unavailable.

The connection between the Toolsee Basin and Vehar will be the same as that in Project No. 2.

After the level of the surface of the Reservoir, has risen to 448·5, all additional rainfall will pass over the waste weir of the small dividing ridge into Vehar, so that Vehar may be said to secure the whole of the rainfall of Toolsee as soon as the level of that Basin has risen to 448·25.

In order to prevent (as in Project No. 2) the Toolsee water from flow-

Nullah leading to Lake

Tunnel

350 on THD

Nullah leading to Lake

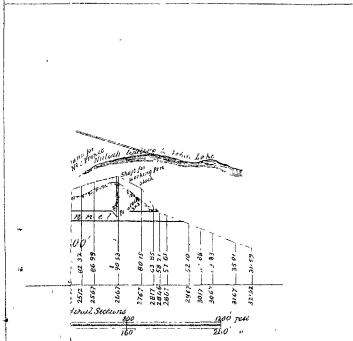
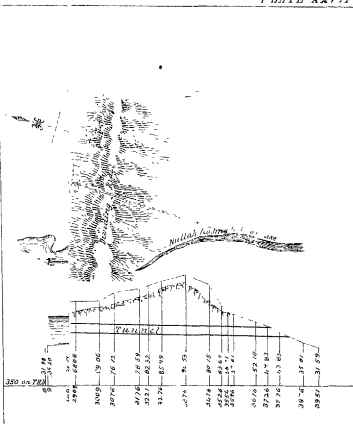
Shaft for working Pen stock

Vertical Sections

800

1200 feet

160

240

It may be remembered that Mr. Conybeare in his second report states, that he is of opinion it would be desirable to increase the gathering-ground of the Vehar works to 5,500 acres, which is almost exactly what any of Mr. Walton's projects would do

With an average rain-fall the gathering-ground of Vehar and its reservoir are fairly balanced, only three times since the works were completed has the latter overflowed, and generally it stands at the close of the monsoon about 18 inches under the waste weir. But an average rain-fall is not what we have to deal with, it is rather a minimum fall, and it so happens that last monsoon we had only half the average, and the lake has now consequently fallen 10 feet below its usual level.

On the whole, I think the time has come when steps should be taken to ensure a full supply from Vehar. Even if the Bench decides on carrying out any of the great schemes which have been so long in embryo, it would be years before they are available, and we require immediate help. I therefore recommend the Bench to acquire and utilize Toolsee.

The Toolsee valley runs into the Kennery valley through a narrow gorge, the bed of which is about 50 feet under the lowest water-shed between Toolsee and Vehar. Any dam therefore which does not exceed this height would not in any way affect the safety of the Vehar dams. Project No. 1 is for a dam 36 feet high and 240 feet in length, with a channel leading into Vehar Project No. 2 has a dam 60 feet high and 400 feet in length, with a similar channel Mr Walton does not recommend, either of these schemes, and I agree with him that if Toolsee is to be utilized at all, it should be so to the greatest extent possible.

Project No 3 has a main dam 74 feet high and 485 feet long, with a channel as in the others, and a second dam on the watershed 1,100 feet long and about 21 feet high. It is essential that the safety of this dam should be put beyond all doubt, as its failure would in all probability cause that also of the Vehar dams. It is, however, of such a small height that this is quite practicable even if it were made higher

Mr. Walton has estimated that No. 3 Project will cost $3\frac{1}{2}$ lakhs of rupees, exclusive of the land. I would, however, recommend the Bench to consider that this will be exceeded, and that it will be more safe to look upon it as a five lakh work, say £50,000 I say this because I think some of Mr. Walton's prices are rather low, and because I would recommend some alterations and additions which will increase the cost, such as

widening the channel in open cutting and increasing the gradient of the adit, providing an inlet tower for an independent main in case it should be required, and strengthening the separating dam. I am also inclined to recommend that the waste weir on the separating dam be dispensed with, and a subsidiary dam formed below the main dam of the Tassoo, so as to form a water cushion as is at present in operation at Kurruckwasla. The supply to Vehar would thus be entirely under command and be regulated by sluices. When the works were completed and in operation, it would probably be considered advisable to keep Toolsee filled as a reserve, running off its surplus water so far as was required into Vehar, or, if that reservoir were full, to waste over the main dam into the Kennery valley.

It will be observed from what I have said, that this project, while it gives an independent *reservoir*, does not so far as described or estimated give an independent *supply*. The question of making it so also does not press for immediate settlement: it can be done either by a separate main into Bombay, which would give a high service supply, or by leading it into the present main somewhere between Coorla and Vehar.

I need hardly say that it is impossible to complete the works before next monsoon, but, if let at once to an experienced and energetic contractor, it is possible to make the conduit and so much of the dams as will ensure, if not all, the greater part of the Toolsee water of next monsoon being turned into Vehar. Even if this be done it will take a heavier rainfall than we have any record of to fill the Vehar reservoir from the united gathering grounds.

Note by T. C. Hope, Esq., C S., Acting Municipal Commissioner.

My own opinion, after visiting the locality, is that Toolsee should be utilized as an increase to the gathering ground of Vehar to the utmost extent of which it is capable—namely, to that of the third or largest of the three projects, but that it would be a mistake to attempt to make it anything more; that is, an independent supply either for annual use, or in the event of the Vehar Dams bursting For the latter purpose it is too small, and the money which would be necessary to connect it with Bombay direct would be far better reserved for a totally separate reservoir of far larger dimensions elsewhere.

Toolsee will thus be simply a reserve to supply the deficiencies of

Vehar from year to year, and the water which may remain over after serving this end in one year, will remain in hand for emergencies perhaps greater in the next. As the water will always be drawn from a low level, the balance in the Lake will be periodically changed throughout and comparatively fresh.

With regard to the financial aspect of the question, Mr Walton assures me that his rates have been taken from Contractors now willing to work on them, and that the $3\frac{1}{4}$ lakhs he names will not be exceeded It would perhaps be safe for the Bench to assume four lakhs as the limit.

No. XXXIII.

BRIDGE FOUNDATIONS ON PUNJAB STATE RAILWAY.

RESOLUTION,—By the Government of India, P. W. Dept.

Simla, 11th September, 1871.

THE Governor General in Council is pleased to direct that a Committee of Engineers shall assemble at Simla forthwith for the purpose of considering the question referred to in the papers now read. It is desired that the Committee will discuss the proposals and opinions contained in these papers, and will make a decided recommendation as to the design that should be adopted for the piers of the large bridges on the Punjab Northern Railway.

As to the design for the abutments, and the general nature of the works that should be devised for their protection, it is possible that the Committee may consider that the information contained in these papers is not sufficient to admit of their offering an opinion with confidence, but even should this be so, the Governor General in Council will be glad to receive such an expression of their views on the subject as they may feel justified in offering, based on their wide professional experience, and their general knowledge of the character of the large rivers to be dealt with.

The Governor General in Council desires that the Committee will meet and report with the least possible delay, but the more pressing question referred for their opinion, viz., the pier design, should be considered first, and their conclusions reported as soon as arrived at, and within, if possible, two or three days from this date.

The Committee will be composed as follows:—

PRESIDENT

COLONEL F. H RUNDALL, R E

MEMBERS.

COLONEL C. W. HUTCHINSON, R E
LIEUTENANT-COLONEL P. P L. O'CONNELL, R.E.
G. L MOLESWORTH, Esq , *Consg Engineer for State Railways.*
A. H. VAUX, Esq., *Memb Inst C.E.*

Report of a Committee assembled by order of the Governor General in Council to investigate the design for the piers of the large bridges on the Punjab Northern (State) Railway.—Dated 14th September, 1871.

Agreeably to the orders conveyed in the Resolution of the Governor General in Council, dated Simla, 11th September, 1871, the Committee assembled on the following day, and thoroughly discussed the proposals and opinions contained in the several papers furnished to them, together with the above orders.

The Committee were directed first " to make a decided recommendation as to the design that should be adopted for the piers of the large bridges;" and next to convey such an expression of their views as they may feel justified in offering, with the information at their disposal, regarding "the design for the abutments and the general nature of the works that should be devised for their protection."

The proposals and opinions which the Committee were called on to discuss in regard to the first point consisted mainly in the relative merits of constructing the piers with a single cylinder, 18 feet, or with two separate cylinders, 12 feet 6 inches in diameter, the depth to which both designs should be sunk below low-water level being the same, viz., 60 feet.

After thoroughly weighing all the arguments brought forward, four out of the five Members of the Committee expressed a decided opinion adverse to the adoption of a single cylinder of any practicable size for such rivers as the Ravee and Chenab, but reserved their opinions with respect to the Jhelum, as there was no reliable information before the Committee as to the material of which the bed of the latter river is composed. They were of opinion that the same amount of material distributed in two or more wells would ensure better distribution of the bearing sur-

face for supporting the superincumbent weight, while in the event of the bed of the river getting scoured, the obstruction opposed to the current when flowing in a direction parallel to the piers by the smaller cylinders would be very greatly diminished.

The Committee, however, considered that a still better distribution would be secured by arranging for three wells, pitched in line at *not more* than 2 feet apart, the two outer wells, being 10 feet, and the centre 12 feet diameter, would, it was believed, diminish still further the obstruction. To this arrangement, which increases the entire mass of material by about 10 per cent., Mr. Vaux, while adhering to his opinion, that the stability of the 18 feet well was equal to any other disposal of the same mass of material, agreed as being unobjectionable The superstructure to be raised on these foundation cylinders, which should be filled up perfectly solid with concrete, the Committee were of opinion should consist of solid masonry.

While thus announcing their conclusions as to the relative merits of the two designs which have been advocated, the Committee feel bound to represent to the Government their decided conviction, that with neither of them can the safety of any bridge founded on such material as is found in the Punjab Rivers (the Jhelum excepted) be *completely* ensured. In the opinion of the Committee, the only principle by which entire security can be obtained in such rivers, whose declivity is comparatively great, is in preventing the bed of the river in the neighbourhood of the bridges from being eroded or scoured. This can be perfectly effected (always supposing that the first principle of sufficient water-way has been provided) by enclosing certain portions of the bed between curtain-walls and connecting those walls with a solid apron or flooring, and further protecting them both up and down-stream with solid material of some description

The design, is based on the necessity for arresting the onward motion of the material of which the beds of these rivers is composed, and which in times of flood partakes of a semi-fluid nature This is the more necessary, as one peculiar characteristic of these rivers is to acquire the additional sectional area necessary to discharge their extreme flood-waters by scouring the bed and extending its width, rather than as is the case with delta rivers in the south of India, by raising their surface level. The rise and fall of the Punjab rivers is comparatively small. The section of the Sutlej at Phillour is a clear illustration of the action which takes place during

flood. The discharge having been ascertained by actual observation, the requisite sectional area or water-way to be given to the bridge is easily determinable, and then in order to preserve that water-way *uniform*, the the protection of the bed from erosion is necessary. The construction of curtain-walls must, it will be readily seen at once, arrest the onward motion of the particles of which the bed is composed, while the flooring consisting of material whose specific gravity is far greater than the velocity of the river can move, effectually prevents any scouring action taking place around the piers, and tends to maintain a uniform velocity of the stream, and prevent any great acceleration of it in any one channel The great obstruction which the unprotected cylinders create when laid bare by the scouring of the bed around them is thus avoided, and all that is opposed to the stream is the comparatively narrow width of the piers, and this again is reduced to a minimum by the addition of finely-pointed cut-waters In this way alone the Committee believe perfect security from accident can be ensured. In the unprotected cylinders arrangement, there is no guarantee whatever that the actions of the flood may not at any time be concentrated in one channel under any one span, and the bed of the river in that span be scoured out to a greater depth than even 60 feet. Consequently it cannot be asserted with any degree of reliability, that any practicable depth to which cylinders may be sunk will prove sufficient to ensure permanent stability. The larger the diameter of such cylinders, the greater the obstruction they present, and the greater the obstruction, the higher velocity of current will they create, and consequently the greater scour will result, and thus the forces at work to undermine the pier are being generated in a continually increasing ratio. The more of the cylinder which is thus exposed, the greater weight will its base have to sustain, while the frictional resistance of its perimeter will be diminished Hence the tendency for the cylinders to subside unequally will be always increasing.

The security procured by protecting the bed from erosion can, however, only be obtained at an increase* of cost, that is, if the unprotected cylinders are to be sunk not more than 60 feet below low-water level, but if sunk 90 feet, the cost would be brought nearer to an equality.

It will be for the Government to determine whether it is worth while to incur the additional outlay in either case in order to obtain that security.

* The relative cost of the two systems will be as 31 to 44.

The Committee believe that they are only called upon to give an engineering opinion on the question, and the opinion which they unhesitatingly and decidedly maintain is, that additional precaution is necessary for the security of bridges constructed in the rivers in question, but of the two methods, they consider that of protecting the bed from erosion as the sounder principle of design. If the design of unprotected piers be adopted, the spans will probably remain unaltered, or about 100 feet, from centre to centre.

If curtain-walls and floorings be used, a reduction in span would be admissible, and a corresponding reduction made in cost of superstructure by the ultimate cost of the two relative designs will be about that mentioned above.

On the second point, viz, "design for the abutments and the general nature of the works that should be devised for their protection," the Committee are unable to offer any reliable opinions in the absence of any surveys or sections of the rivers, or any calculation or observation as to their flood-volumes and other particulars, a knowledge of which is essential in order to arrive at any idea of the extent or the form which such protective, or rather training works should assume The requisite information has been called for by telegraph, and on its receipt, the Committee propose to re-assemble In the meantime, they submit without delay, agreeably to the orders they have received, the conclusion at which they have arrived as regards the pier design

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Note by A. H VAUX, ESQ., *Member of the Committee* (*State*) *Railway.*

Dated 15th September, 1871.

I concur generally Platforms at low-water level with deep curtain-walls are known successfully to protect the beds of rivers. The efficacy of such platforms was discussed and acknowledged by Government when the beds of the streams draining the Rajmahal Hills were being protected some years ago by the East Indian Railway. The platforms were costly but successful, and experience convinces me that, even in very large rivers from an engineering point of view, the precaution is perfectly sound in principle if the flood discharge below dry-weather level is small when compared with the whole discharge of the river.

My preference for a single cylinder of 18 or 18½ feet diameter, instead

of three wells in line, of 10, 12 and 10 feet, is founded on my belief that the single well, which contains the same bulk as the three small wells, presents a less surface on which friction will act, and that it can, therefore, bulk for bulk, be sunk more readily and deeper than the three small wells. For the same reason, the chances of injury from meeting obstructions in the process of sinking are less in the larger than the small well The exposed surface in the three wells, as compared with the same bulk in one well, is as 64 to 37 The comparatively large amount of space for working within the large single cylinders also facilitates the process of sinking. Could we sink all the wells to the same depth, and could we ensure that no damage should accrue during sinking, I believe that three wells would be as good as, but no better than, the single well. We know that the flood discharge below dry-weather level is trivial in the Chenab and Ravee when compared with the whole discharge of those rivers, and I attach but little importance to the objections which have been urged as to the obstruction caused by the increased diameter of the large well. Above low-water, the piers will be alike in obstructive width, whatever be the nature of the foundations. I would use up the small curbs which are on hand, and thereby avoid delay, but I would make no more.

Second Report of Committee on the subject of the designs for Punjab Northern Railway bridges over Ravee, Chenab and Jhelum Rivers.

Dated 13th October, 1871

On the 2nd instant the Committee re-assembled for the consideration of further points connected with the construction of the bridges on the Northern (State) Railway. Having the advantage of conferring with Colonel Pollard, the Consulting Engineer, and Mr. Grant, the Chief Engineer, as well as being in possession of much additional information, the Committee took up the following points :—

1st.—The amount of water-way necessary on each of the Rivers Ravee, Chenab and Jhelum.

2nd.—The design for the abutments.

3rd—The description and extent of training works in each case.

4th.—The design of piers for the Jhelum Bridge.

According to the gauging of the Rivers Ravee and Chenab, which the Chief Engineer assured the Committee were taken from actual observations

of a reliable character, the flood discharges during exceptional floods appears to be 183,000 and 384,000 cubic feet per second, respectively. Assuming that the maximum observed velocity, 6·25 and 6·50 feet per second, were not exceeded through the bays of the bridge, the sectional area necessary would be 29,280 and 60,000 square feet, respectively. The water-way provided on the designs amounts to 32,000 and 70,000 square feet, so that, if the provision errs, the error is slightly on the side of excess.

The discharge of the Jhelum had not been recorded with the same degree of reliability, and therefore the Committee cannot express the same decided opinion in regard to the provision which has been made for this river, but, as far as they could arrive at a conclusion, sufficient water-way seems to have been allowed.

On the second point—the design for the abutments and wings—after considerable discussion the Committee considered that the principle to be adopted should be to construct them, so that, in the event of any breach occurring in the embanked approaches owing to a sudden and unfavorable set of the river, or by the creation of a parallel current, there should be no risk of the abutment being undermined, and that the injury should be confined to the earthwork, which would involve only a temporary interruption of traffic, and be capable of repair as soon as the floods subsided.

With this view, two alternative plans, have been suggested, the former of which commended itself to the majority of the Committee as combining the greater elements of safety; the latter, suggested by Mr. Molesworth, possesses the advantage of economy, but opinions were divided as to its combining therewith the quality of safety.

The President and Colonels Hutchinson and O'Connell and Mr Vaux are in favor of the more expensive alternative, consisting, in fact, of an extension of the curtain-walls and flooring for a length of 75 feet behind the abutment, so as to protect the latter in the event of any breach occurring from any cause in the embanked approach of the bridge, and thus providing completely for the safety of the abutment. Plan No 2 in the opinion of the Committee, is not compatible with the shallow foundation system.

The cost of proposal No. 1 is estimated at Rs. 41,396; that of No. 2 at Rs. 21,031.

Whichever of the two plans for abutment and accessories the Government may see fit to adopt, will be applicable equally to the Chenab as to the Ravee.

In the event of the deep well system being selected by Government, it would be imperatively necessary that three bridge spans at least adjacent to the abutment, should be protected by flooring, the cost of which was not included in our former Report when instituting a comparison between deep and shallow foundations.

The third point, viz.,—the description and extent of training works—were thoroughly considered, and the following conclusions arrived at in connexion with each river.—

First, as regards those for the Ravee.

The measures which had hitherto been carried out on that river, viz., a series of dams across what is termed the back-channel, were considered wholly unsuitable

In the first place it is evident that this channel, which carries off the drainage of the city of Lahore, ought not to be closed

If this nullah were shut up at the head, and none of the river-water allowed to flow down it, it is certain that its lower end would gradually be closed up, and that the drainage of the city would then remain in the nullah, which would become at once a stagnant, and very soon afterwards, an offensive pool, dangerous to the health of the City and Cantonment of Mean Meer. If the nullah be left entirely open, there would be the risk of its one day again becoming the main channel of the river, as it has evidently once been.

If protected only with a head-work, that work would always be in danger of being turned, as the head bund has been this year, and the river might open a new head which would in time enlarge dangerously, the Committee, therefore, recommend that a masonry head-work, consisting of a bridge of two 30-feet arches protected by a good flooring and curtain-walls, be built at the spot indicated on the plan, and that an embankment be carried from it along the highest ground as far as the Railway embankment, in order to prevent the head-work being out-flanked. This bank should have a long slope on the river side of certainly not less than 3 to 1, (and better were it 5 to 1,) protected with what are locally termed "tungas" and brushwood spurs, so as to intercept the river silt and cause its deposition, so as gradually to raise the level of the island above that of the floods.

As the depth of water on the island is not more than 3 feet, there will be but a very slight current parallel to the line of embankment, and it will be still further deadened by the spurs.

Instead of a solid embankment being carried across the nullah in the line of the Railway, the Committee recommend a bridge of three 40 feet spans, protected by a flooring and curtain-walls, which will be sufficient to provide for the local drainage in addition to the quantity allowed to enter the head of the nullah from the river itself.

For the right bank, the proper work would seem to be to restore the portion of the enclosure wall of the Shah's tomb, which has been carried away, founding it on deep wells, connecting the garden wall with the village of Shadra, and running out spurs from that village so as to deflect the current from off the garden wall as much as possible.

These works seem to the Committee sufficient to ensure the protection of the natural line of river-bank, but it will be necessary to watch the river-beds also for some years to come, and not allow the growth of islands to take place. In the event of there being any such tendency, channels should be cut through the sand-banks immediately the floods subside, and the cold weather stream sent through them, so as to keep them open against the arrival of the floods of the following season.

With these precautions, the Committee believe the Ravee may be kept in proper train.

As regards the Chenab, the training works already undertaken having proved successful, should be maintained as they are, with the exception that it will be expedient to connect the spur on the right bank with the high ground to prevent its being out-flanked. The design for the abutments, as before observed, may be similar to those adopted for the Ravee, and the bridge itself be treated in a precisely similar manner

As regards the River Jhelum, the Committee were unable to make any suggestion in their former Report for want of sufficient information. Since then, sections showing the soil found by boring, and plans of the river itself, have been received.

From a consideration of these, the Committee are led to make the following recommendations :—

As regards the training works, they are agreed that the plan hitherto adopted is that which should be followed as far as their alignment is concerned, but they are of opinion that the proposal to make them of a more

permanent character, by the construction of deep wells, is unnecessarily expensive, and that the same object would be more cheaply and equally well, if not better, attained, by the substitution of crib-work filled with the boulders found in the river and so disposed, as in the event of any erosion taking place, they may fall at once into the hole thus scoured.

They think also that it is more expedient to train the river properly than to increase the water-way of the bridge, and allow the river to wander, as there is no guarantee against its filling up some of the spans, and deepening others abnormally, whereas, if kept in proper train, no such action is likely to occur. Of the sufficiency of the water-way provided, the Committee are, as before said, unable to pronounce an opinion, as the requisite data for forming a judgment on this important point are not available. Both Colonel Pollard and Mr Grant, however, seemed satisfied that the present design sufficiently provided for the highest floods.

With regard to the question of the best design for the piers, the Committee were divided. Messrs. Molesworth and Vaux consider that single cylinder piers of from 12 feet 6 inches to 15 feet diameter would be better than the three cylinders advocated by the other Members of the Committee, who would prefer oblong piers with cut-waters raised on the foundation of three cylinders of 12 feet and 9 feet diameter, respectively.

As shingle is met with at no great depth in this river, the Committee do not think a protective flooring necessary, except for three spans adjacent to the abutment on the left bank which they would recommend being built with precautions similar to those proposed for the Ravee.

The Committee, believing that they have now considered all the points referred to in the instructions received from Government, trust the recommendations which have been made will prove satisfactory.

RESOLUTION,—By the Government of India, P. W. Dept.

20th December 1871.

RESOLUTION—His Excellency the Governor General in Council has carefully considered the Reports on the designs of these large bridges with the aid of the Reports of a Committee of Engineers assembled at Simla, and has arrived at the following conclusions:—

I.—There appears to be no reason to alter the design or length of the spans of iron-work already ordered from England.

II.—The water-way of 97 spans provided for the Chenab appears un-

ple. That of 33 spans for the Ravee is less certainly sufficient, but there appears no reason at present for adding to the water-way. For the Jhelum both from the large drainage area of the river, and the somewhat critical position of the left abutment, His Excellency in Council has decided that 50 spans should be constructed, instead of 13 as previously settled.

III.—In regard to the piers of these bridges, in supersession of the orders contained in Public Works Department, No 1176 R, dated 12th August 1871, at the Ravee and Chenab each pier shall consist of three 12½ feet wells sunk 70 feet, or as far as possible, and protected all round with brick-rubbish or boulders thrown in to the extent of at least 30,000 cubic feet to each pier.

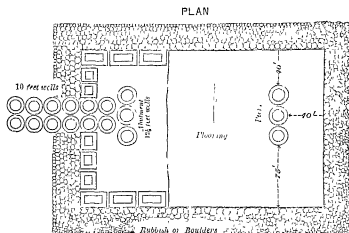
In regard to the Jhelum, where a bed of boulders extends all along the breadth of the river at a depth below the dry-season level of about 22 feet on the left, and 15 feet on the right side, it is now decided that three wells should be given to each pier, one of 12½, and two of 10 feet diameter, that they should be sunk 6 or 8 feet into the boulder bed, and that no further protection need be given.

IV.—As regards abutments, His Excellency in Council decides that the abutment proper in each case shall be similar to the piers, but that behind it there shall be a pair of retaining walls run out on 10 feet wells parallel to each other, in continuation of the direction of the bridge for a length of 75 feet. The wells for these retaining walls should be sunk 40, 30 and 20 feet in the case of the Ravee and Chenab, those neares[illegible] th abutment being sunk the deepest. For the Jhelum, the retainin[illegible]-wall need only be given on the left bank, the wells being sunk to t[illegible] same depth as those of the piers.

For the further protection of the abutments of the Ravee a[illegible]nd Chenab, His Excellency in Council desires that a brick-flooring, 3[illegible] feet thick, be laid round each abutment, and one pier nearest to it, protec[illegible]ted by a curtain of deep blocks all round: the line of curtain blocks being[illegible] 10 feet from the wells of the piers and abutment on the up-stream side, [illegible]o and 75 feet from the wells on the down-stream side, and extending 40 fee[illegible] beyond the pier on the one side, and 40 feet beyond the abutment on the o[illegible]ther side. The line of curtain blocks should be 20 feet deep on the sides p[illegible]arallel to the stream and on the down-stream side, and 10 feet deep on the [illegible] up-stream side. All round the flooring outside the curtain blocks there [illegible] should be thrown in boulders or brick-rubbish at 200 cubic feet to the foot [illegible] of

curtain blocks where they are 20 feet deep, and 100 cubic feet to the foot-run where they are 10 feet deep.

The general arrangement of this protection work is shown in the accompanying sketch.

PLAN

The slopes of the Railway embankment joining the abutments should be pitched on both sides with brick or kunkur blocks, or boulders for 100 yards, and a mass of such blocks should, besides, be accumulated round the end of the embankment where it joins the abutment, both on up and down-stream sides, to the extent of 50,000 cubic feet on each side.

Similar masses of boulders should be laid at the left abutment of the Jhelum Bridge.

V.—As regards training works, those in progress at the Chenab Bridge site are entirely approved. Those at the Jhelum are also approved, with the modification that no masonry works are to the constructed, but the parts requiring greater permanence are to be constructed of crib-work filled with boulders. At the Ravee it appears necessary to restore the portion of the enclosure wall of the tomb at Shahdera, which has fallen away, founding it on deep wells, protected by a talus of brick or kunkur blocks and crib-work. On the left bank, His Excellency in Council thinks it best to give up the project of closing altogether the back channel, and to place a bridge of 20 openings of 6 feet in the Railway embankment, provided with shutters to close it, if desired. The bridge shoul

have a good flooring and curtain blocks up and down-stream. A similar bridge of ten openings of 6 feet should be built to form the permanent head-work of the channel, so as to regulate the entry of water from the river. The water should be prevented entering from the river otherwise than by this head, by the construction of an embankment along the highest ground to meet the Railway bank, having a slope of not less than 4 to 1 to the river which should be protected by brushwood spurs and tungas

No. XXXIV.

IS IRRIGATION NECESSARY?

A reply to Major Corbett's Articles, entitled "Is Irrigation Necessary in Upper India?" published in Professional Papers on Indian Engineering, Vol. I., Second Series, Parts 1 *and* 2. BY CAPT. C. S. THOMASON, R.E.

Agra, 13th December, 1871.

Is Irrigation Necessary in Upper India? Such is the title of a pamphlet by Major A. F. Corbett. The question thus raised is of such vital importance, and there is so much truth in the arguments advanced, that it cannot be a subject of astonishment that His Excellency the Viceroy should be anxious to have the subject fairly discussed in order to ascertain whether the conclusion arrived at by Major Corbett, "that irrigation is not necessary" is a correct one or otherwise.

Briefly the pamphlet states that:—

Under the Indian system of husbandry with shallow ploughing, a hard pan caused by the tread of men and cattle immediately underlies the cultivated surface soil, prevents the access of water and air to the subsoil, and presents an impenetrable barrier to the progress downwards of the roots of plants. That the effect of irrigation on such a soil is to harden, and as it were, glaze it, rendering repeated waterings necessary to overcome the evil Again the effect of this surface hardening and glazing causes a radiation of heat from the earth's surface which adds materially to the heat of the temperature, and thus seriously affects the rain-fall which is the country's due. It is further argued that irrigation as at present practised and under such circumstances must cause malaria.

Major Corbett's panacea for these evils consists of deep ploughing and manuring; but chiefly deep ploughing, which he claims can be economically effected by means of a slight modification of the native plough, which he himself has tried successfully.

The views of the late Colonel J. C. Anderson, R.E., Inspector General of Irrigation, in reply to Major Corbett's pamphlet are appended and may be thus summarised —

Referring to an experiment on deep culture, on which Major Corbett lays much stress as proving his argument, it is shown that much must undoubtedly have been due to a heavy manuring which was given to the land at the same time—so much in fact, as to vitiate the experiment as one on deep culture alone. The inability of irrigation and other water to percolate the pan alluded to by Major Corbett is disputed, as it is a well known fact that the spring level in wells rises considerably on the introduction of irrigation into a district. The advisability of deep culture for all but "bhoor" or sandy soils is admitted, but its value as a substitute for irrigation is held to be anything but proved.

Colonel F H Rundall, R.E., Officiating Inspector General of Irrigation, whose opinion also accompanies the pamphlet, quite agrees as to the enhanced productive value of land deeply ploughed and manured, but thinks that if deep ploughing renders the moisture in the soil more accessible to the plant, it could at the same time hardly fail to expose the soil more directly to the influence of the sun's rays, and thus cause the soil to be more rapidly dessicated than with shallow ploughing. He recommends deep ploughing combined with irrigation, it being a well acknowledged principle of farming that *the more water that can be passed* THROUGH *the soil the better, so long as it does not remain* IN *it.*

A quotation from a report of Mr. Halsey closes the pamphlet. Mr. Halsey believes so firmly in the advantages of deep ploughing, that he recommends it as a substitute for manuring. Thus the argument seems to stand at present. Let us see what more has to be said on the subject. First, as to the pan stated by Major Corbett immediately to underlie the cultivated soil, and to be impermeable to water or air, but proved by Colonel Anderson to be permeable by irrigation water. No one conversant with agriculture will doubt the existence of this pan, at least in any but very light soil. How then does the irrigation water penetrate this pan? Is it not possible that this water may seek its way through fissures, which abound in such soil, and still that it may not be available for the *nourishment* of the plant owing to the pan intervening? Colonel Anderson's argument hardly clears the *pan* of the charge preferred against it and as Major Corbett, Colonel Anderson, Colonel Rundall, Mr.

Halsey, and every other known authority advises its demolition, by all means let us get rid of it wherever we can.

But how is this pan to be demolished ? Major Corbett says the natives have a prejudice against deep ploughing (page 11), and he attributes this prejudice chiefly to laziness. The natives are not by any means the only objectors to deep *ploughing*. Many good farmers at home object to deep ploughing under *all* circumstances, and would most certainly object to it in a deep stiff clay without precautionary measures hardly hinted at by Major Corbett. An Indian field of stiff clay if only deeply *ploughed* would simply be ruined for the time being. The experiment has been tried in India before now, and the result has often been quoted as a conclusive argument against deep cultivation. Probably the soil was heavy, working in which the steam plough would simply bury the seed bed, turn up the worthless subsoil and give the cultivator seven or eight, instead of three inches of unaerated mud in the rains No good crop could be expected under such circumstances. If the sub-soil were porous, the result would be be an improved crop, but still nothing like so good as it might be In the former case, Major Corbett is quite right in saying that irrigation is not required; for it would only make matters worse. In the case of a porous subsoil, irrigation would certainly confer a great benefit; for the water would not stagnate about the roots, and air would follow the water in its course downwards. In both cases, however, would the malaria be increased, for in neither is provision made for the *circulation* of air in the soil, and the moisture gradually evaporated in a stagnant sub-soil atmosphere, would be in excess of what it was before. Major Corbett has quite overlooked the most necessary preliminary to deep cultivation, and that is *sub-soil drainage*.

No English farmer now would ever dream of deeply cultivating *any* land without previously subsoil draining it. Though new to, and discredited by us in India, it is everywhere else,—that is wherever farming is scientifically carried on—considered the unfailing preliminary to all improvement. The processes in their order are,—(1) surface draining, (2) subsoil draining, (3) sub-soil ploughing or cultivating without turning over, and (4), if necessary after some years when the nature of the sub-soil has been completely changed by improved husbandry, deep *ploughing* or turning down the original seed bed.

Deep *cultivating* and not *ploughing* is evidently what Major Corbett ad-

cates, judging from his improved plough, but the two terms are by no means synonomous, as will be seen from the foregoing. Deep *ploughing* is comparatively little resorted to now, the steam digger (a powerful kind of *cultivator*) generally taking its place in England.

Without in any way disparaging Major Corbett's ingenious modification of the common native plough, such an implement can hardly be considered adequate to our requirement if deep cultivation is to be the rule. For the purposes of preliminary experiment let it be tested by all means; but if the experiment prove successful, considering the immense area to be operated upon, why stop short of steam, the economy of which on such a large scale admits of no dispute; steam becomes doubly necessary where subsoil drainage is superadded to deep cultivation, the extra cost of the former in such cases being but trifling.

To prove the truth of what was here asserted as to sub-soil drainage, let the reader take a rose or any other plant, pot it with the most favorable mould, water it, and foster it in every conceivable way. His care will avail little if their be no hole in the bottom of the flower pot. The more he waters it and manures it, the quicker will the plant die. There is no sub-soil drainage, and the roots rot in a stagnant sub-soil atmosphere. A hole in the bottom of the flowerpot gives sub-soil drainage, gives air and changes all, the plant, if not quite killed by previous mismanagement, speedily reviving and thriving beyond expectation.

Had Major Corbett advocated deep cultivation preceded by sub-soil drainage there is little in his pamphlet that could be disputed except the statement that such treatment of the soil entirely dispenses with necessity for irrigation. All known experience goes to prove, (1), that sub-soil drainage combined with deep cultivation enables the land to withstand without injury droughts, excessive waterings, &c., that prove the ruin of fields not enjoying these advantages, and (2), that with such preliminary treatment the land will better absorb and retain for purposes of growth all fertilisers that may subsequently be bestowed upon it, whether rain, irrigation water (surface or sub-soil,) or manures.

The irrigation duty of water is certainly doubled by sub-soil drainage, if English experience goes for anything; and such being the case, the expediency of extending existing canals, and of having recourse to fresh supplies of water until experiments with the sub-soil have been fairly tried in India may fairly be called in question.

The above assertion that "sub-soil drainage, combined with deep cultivation, enables land to withstand drought" will appear so incredible to those who have not studied the subject, or had occular demonstration of its truth that some explanation of such an apparent paradox appears necessary.

Let us imagine a field in India under irrigation. The water covers the field to a depth of two or three inches, and so it is left an unmistakeable field of mud some six or seven inches deep. Below the "pan" the water will not sink except partially, and so it is almost entirely evaporated by the sun; and unless the watering be speedily renewed, the soil down to the pan being but shallow, and readily acted on by the sun's rays, soon becomes as hard and dry as the pan itself, cracking in all directions.

Again, let us suppose this same field supplied with sub-soil drains, say three feet deep, and the cultivation extending deep enough to break up the pan The water now will no longer lie on the surface, it passes through the surface soil, through what was pan, and moistens the whole soil, down to the level of the sub-soil drains, and even lower In its passage downwards the water carries air; and, most important of all, the minute pores created by the passage of the water permit the continued gentle circulation of air in the sub-soil after the running water has passed through the drains. We thus obtain three feet of soil wholesomely moist and ærated, and knowing this, we need no longer wonder that the sun's rays take so long to exhaust the moisture of this soil when elsewhere all is parched. The water that has moistened the three feet of soil in the second case, is what in the first case would have wetted six or seven inches deep, and been speedily evaporated. Hence the increased irrigating duty of water on sub-soil drained land

Reverting to Colonel Rundall's apt quotation of the acknowledged principle in farming, that "the more water that can be passed *through* the soil, so long as it is not allowed to remain *in* it"—if a pan underlies soil, how can the water be efficiently passed through the soil without sub-soil drains?

Without going so far as Major Corbett apparently wishes us to, in asserting that our hot winds and extreme heat are entirely due to shallow cultivation and irrigation, it may safely be conceded that deep cultivation will avert a considerable amount of heat radiated from the earth. Sub-soil drainage carries the moisture, and virtually the cultivation deeper than the reach of the plough, and therefore enables the earth to absorb

still more and radiate still less of the heat. This effect is a well established fact. Sub-soil drains in England protect the crops from frost, why should they not protect the cotton against this enemy in the N. W Provinces.

It will be seen from the foregoing that the fundamental laws of nature as evinced in the beneficial effects of sub-soil drainage should be as applicable to India as to England. Why then is sub-soil drainage ignored here, seeing that it promises to be almost as important an agent in averting famine as irrigation is?

Though no valid reason can possibly be assigned against a trial of sub-soil drainage on differing soils and crops, on a small scale and at a trifling cost, its impracticability is strongly urged on three grounds, viz.—(1), Frequently a want of a fall in the land; (2), A general drought is anticipated from its introduction; and (3), Its cost

First, as to want of fall—Sub-soil drainage is universal in England—even in the flat marsh and fen lands of Lincolnshire. Where irrigation water will run, sub-soil drainage water surely will Therefore, if there is not sufficient fall for sub-soil drains, the surface drainage is clearly deficient, and the sooner that is rectified the better No one disputes the necessity for efficient surface drainage.*

Secondly, as to the anticipated drought.—This objection has already been answered, but be it borne in mind that the arguments are only generally applicable where sub-soil drainage and deep cultivation are combined.

Apropos to this part of the question and Major Corbett's assertion that, "the opinion is gaining ground that sub-soil drainage has been overdone in England," is a very interesting correspondence in the *Times* during the drought of June and July 1870, particularly a letter on the "Lessons of the Drought," by Mr Scott, in the *Times* of July 6th. If that correspondence proves anything, it proves that the chief sufferers were not those who had sub-soil-drained, but their neighbours who had *not* sub-soil-drained. All however cried out for storage of water and irrigation in England. How then can we dispense with irrigation in Upper India?

Thirdly, as to cost.—Without lengthening this paper unnecessarily

* If steam ploughing be conceded, a very great deal of even this surface drainage might be very economically effected by working a "Fowler's Ditcher" by means of the steam plough tackle At the Royal Agricultural Society's steam plough trials, near Stafford, May 8th, 1871, one of these ditchers in a stiff soil efficiently cut ditches about two feet deep, three feet wide at top, and eight inches wide at bottom. Unfortunately I had not an opportunity at the time of making notes to arrive at cost, though an immense saving over manual labor was self-evident.

with the details on which the estimates are founded, but which are given in Appendix, the following may be safely accepted as the average costs of sub-soil draining and deep cultivation Supposing some soils to require pipes and some simply the steam draining plough, the average depth of drains to be 3 feet, and the distances between drains 18 feet, the cost with manual labor per acre with pipes will be Rs 20 per acre; steam cultivation 8 or 9 inches deep, Rs. 5 per acre; similar steam cultivation with sub-soil drainage also effected by steam costing, where no pipes are required, Rs. 6 per acre, and where pipes are necessary, Rs 17 per acre.

Supposing the average gross value of land for cereals to be taken as low as Rs. 15, for the higher classed crops (such as sugar-cane) at Rs. 30 per acre, and the yield to be doubled by the improved husbandry here proposed,—a very moderate estimate,—it surely is not difficult to imagine from whence the funds are to be derived, whereby to sub-soil-drain the culturable, or at least irrigable land of India. Let the experiment—a simple enough one in all conscience, be but once tried, and there need be no fear of its extending in India as in England, if what is here asserted is any approximation to the truth.

For sub-soil-draining and deep cultivating with steam, an expenditure of Rs. 6 per acre is here advocated. The expenditure thus incurred, (as in England with sub-soil-drainage,) might be recovered, capital and good interest, by small annual payments by the cultivator, not only without inconvenience, but with immense advantage to him, and ample remuneration to those advancing the money for the outlay. But what is the case with our existing irrigation works which we rightly so value as to grudge little for their extension?

According to the Irrigation Reports for 1868-69, the Ganges Canal up to date may be said to have cost Government roughly $3\frac{3}{4}$ millions of pounds, and only then to have been yielding 1·3 per cent. direct profit on outlay. The expenditure that year did not amount to Rs. 4 per acre irrigated; but the year was an exceptionally favorable one for the canal. Probably Rs 5 per acre irrigated may represent the present expenditure, and not very long before the date above quoted, at least more than twenty years after the commencement of the construction, the expenditure must have been very considerably in excess of what is here advocated for sub-soil-drainage and deep cultivation, the profitable returns from which are immediate.

Rightly or wrongly, our canals get credit for originating an untold amount of malaria and disease, and if the facts as to the cost, &c., of sub-soil-drainage and deep cultivation, the well-known antidotes to this malaria, are found everywhere else to be as here stated, is it not incumbent on us to try the experiment in India, and, should the experiment prove successful, not only enjoin the extension of such improved husbandry, but even hereafter in time make it obligatory wherever canal irrigation is carried on?

To satisfy the sceptical as to the *results* of deep cultivation and sub-soil drainage, the first experiments might easily be effected with deep cultivation, with sub-soil drainage, and with both combined, by manual labor on three or four acres of different class soils in juxta-position to a similar acreage cultivated in the ordinary way with and without irrigation, and so much the better if a tract of *reh* soil be selected for the experiment. The main questions to be settled in the first place are—(1), The irrigating duty of water, (2), The benefits derivable without manure, (3), The benefits derivable with manure; (4), The effect on the reh; (5), The necessity or otherwise for Irrigation in Upper India.

If the question of *cost* be the stumbling block, Government is already in possession of by far the most expensive portion of the apparatus for a trial with steam.

There are lying idle at Bareilly, a 10-H. P. traction engine by Clayton and Suttleworth, and a B 1 centrifugal pump by Gwynne. All that is now required is Fisken's apparatus and tackle, with Fowler's cultivator, digger and ditcher, the whole probably costing Rs. 3000.

At the Stafford trials in May 1871, a sister engine to the Bareilly one proved itself capable of accomplishing as hard work in ploughing with Fisken's apparatus as even Fowler's far more powerful engines—two of 20-H. P.—working Fowler's system, though of course the speed was much less in the former case. The Judges' award went to Messrs. Fowler; but it is quite possible that the decision might have been different, had the trials taken place in India, where the wearing parts of Fisken's tackle (chiefly Manilla rope) could be so easily replaced, not to mention the great advantage as to first cost, weight, and portability which Fisken's system possesses.

The Gwynne's pump at Bareilly might prove valuable, if not necessary, to settle the question of the "irrigating duty" of water applied to soil cul-

tivated on the existing system as compared with the improved system proposed.

Such questions as those relating to climate, health, &c., protracted experience of operations on a large scale can alone solve

Assuming such to be the case, advances by Government to cultivators and assistance in sub-soil draining their land are certainly as legitimate applications of public money as the extension of canals, which most probably have not yet done half their duty, and must do it all before they cease to poison the air with malaria.

In the interests of irrigation can there be a more important question to settle than the treatment of the "Reh" lands, extending year by year throughout our irrigated districts* and rendering our irrigation worse than useless? Sub-soil drainage combined with deep cultivation is the rational remedy for the evil complained of—more than that—it is the only known practical remedy. It has been tried and proved successful by a private individual on a small scale at Lahore at least; and it is almost inconceivable that a persistent reiteration of theories opposed to reason and fact should have sufficed hitherto to forbid a very inexpensive public experiment to solve this question of such national importance.

Finally, the conclusion we arrive at is—That Major Corbett is right in demanding deep cultivation; but that, according to all known precedent, such cultivation should be preceded by sub-soil drainage: and that though sub-soil drainage and deep cultivation cannot be regarded as substitutes for irrigation, precedent tends to prove that the two combined are efficient economisers of canal water, and, experimentally at least, as worthy of the attention of Government as the extension of canals that have not yet done half their duty.

Cost of steam Ploughing.

(1.) Smith of Woolston's round about system as actually observed at Elkington, Lincolnshire, April 30th, 1870, on soil which in India would be classed as "doomunt," second ploughing from 7 inches deep to 10 inches deep. Engine a 12-H. P. agricultural single cylinder with double expansion valve, by Tuxford, working at 60 lbs. pressure, cost £280. Cultivating tackle cost £170. Steel wire rope 1,400 yards cost £50. Total £500.

* *Vide* Mr. Sherer's report on the Western Jumna Canal districts, submitted to Government in 1856-57, and many other reports. From personal observation, I can testify to the rapid extension of "*reh*" land in the Bareilly district from 1863 to 1868.

	In England Actual.			In India Estimated		
	£	s.	d.	Rs	A.	P.
Engine, ...	280	0	0	3,700	0	0
Tackle, ...	170	0	0	2,300	0	0
Wire rope, ...	50	0	0	680	0	0
Totals, ...	500	0	0	6,680	0	0
or say,				6,700	0	0

Cost of working per day of 10 *hours*

	In England Actual			In India Estimated.		
	£	s.	d	RS	A	P.
1 Engine driver, ...	0	3	6	0	8	0
1 Man at drums, ...	0	2	9	0	6	0
2 Men at anchors, ...	0	5	0	0	8	0
1 Man at plough, ...	0	2	6	0	6	0
2 Boys or porters, ...	0	1	8	0	6	0
1 Man for water and general work, ...	0	2	6	0	4	0
Fuel, { 7 cwt. coal, ...	0	2	4			
Fuel, { 20 maunds wood, ...				5	0	0
Oil and waste, ...	0	1	0	1	0	0
Depreciation, wear and tear, interest on capital &c., of Engine, ...	0	2	0	1	6	0
Depreciation, wear and tear, interest on tackle, rope, &c., ...	0	5	3	3	8	0
English supervision and other contingencies possibly peculiar to India, ...				1	13	0
Totals, ...	1	8	6	15	0	0
or say,	1	10	0	15	0	0

The work done at Elkington on April 30th was ten acres in a day of 10 hours, which gives a rate of 3*s.* per acre. The first time of ploughing down to 7 inches deep, the work done per day was said to be 5 acres, which gives a rate of 6*s.* per acre; so that the two ploughings together cost 9*s.* per acre, or say 10*s.* or Rs 5 per acre, allowing for possible omissions. The actual cost in England and the estimated cost in India, may be taken as the same.

Notes on the steam ploughing at the Royal Agricultural Society's Exhibition at Wolverhampton, where the soil was stiff, give rates higher than this; but such stiff soils are quite exceptional.

A report in the *Scotsman* of 2nd March, 1871, on direct action plough with Thomson's road steamer at Dunmore Park, assigns 2*s.* 9*d.* per acre

for ploughing autumn stubbles, and 3s. 10d. per acre for spring ploughing; but the statement gave rise to much controversy in the papers, and this question of direct action ploughing must still be considered as an open one.

Fowler's system and Fisken's system both claim to be better than Smith's; but that is not a question to be entered into here. The only object is to show what the cost of steam ploughing need not exceed by well-known, well-tried and efficient methods.

Estimate of sub-soil draining per acre in India.

Drains to be composed of 2-inch drainage pipes, 15 inches long, laid 18 feet apart and 3 feet deep. Sectional area of cutting $2\frac{1}{2}$ superficial feet.

Excavation and refilling

$2420 \times 2\frac{1}{2} = 6{,}050$, or say 6,000 c. f., @ Rs 1-8, ...	9	0	0
1936 2-inch pipes and collars, or say 2,000 pipes, @ Rs. 5, ...	10	0	0
Contingences, ...	1	0	0
Total,	20	0	0

Where a steam plough is available, in most instances the sub-soil draining might be done by means of a special plough worked at 18 feet intervals, sub-soil draining and deep cultivation being in such a case effected at very nearly the same cost as deep cultivation alone. No pipes will be required for this system of sub-soil draining.

In some cases pipes will be found indispensable for sub-soil draining, and may be laid by means of steam and Fowler and Fry's pipe draining plough. One rupee per acre would probably suffice to cover the cost of excavating the small pits excavated at short intervals for the introduction of the pipes, and in this case the cost might be estimated thus per acre:—

Hand excavation, ...	Rs.	1	0	0
Machine work of sub-soil draining and deep cultivation, ..	„	6	0	0
Cost of pipes, ...	„	10	0	0
Total, ...	„	17	0	0

Abstract of Estimates.

Deep cultivation and sub-soil draining by steam without pipes, per acre, ...	Rs.	6	0	0
Ditto ditto, with pipes, ...	„	17	0	0
Deep cultivation alone by steam, ...	„	5	0	0
Sub-soil draining with pipes by hand, ...	„	20	0	0

C. S. T.

No. XXXV.

IRRIGATION EXPERIMENTS.

[*Vide* Plates Nos. XXVIII., XXIX., and XXX.]

Report of certain experiments made on the discharge and irrigating power of various forms of pipes or outlets on the Baree Doab Canal. By E. C. Palmer, Esq., C.E., *Exec. Engineer.*

In compliance with instructions conveyed in Superintending Engineer's No. 2809, dated 12th December, 1867, the following experiments were made :—

1*stly.*—On the discharge of muddy canal water through orifices, or rather, short tubes, having a length of 15 feet, the average length of the heads of the private water-courses on the Baree Doab Canal, &c.

2*ndly.*—On the time required to thoroughly saturate an acre of ground with the same orifices working under the same heads of pressure. The latter experiments were repeated on different descriptions of land.

3*rdly.*—For the sake of comparison with the above, the discharge and irrigating powers of jhullars (machines for raising water with small lifts) and wells.

These experiments were made by myself and my brother Captain Palmer, Executive Engineer, 2nd Division, Baree Doab Canal, so far back as November 1867, but we have not had leisure from our current duties to prepare the report sooner.

Before alluding to the experiments, it is necessary to describe as accurately as possible, the conditions under which they were made, and the apparatus employed. Near the village of Chevinda, in the Umritsur

District, and within a quarter of a mile of the Ahwal rajbuha, lies a masonry tank, having a sluice by which the water may be run off into a neighbouring pond, from the sill of this sluice to that of another, by which water is admitted from the rajbuha, is a height of 6·6 feet. A sketch of the relative position of the tank, rajbuha and supply channel is given in *Plate* 28. The arrangement of the pipes whose discharges were observed, is shown in *Plate* 29

The method adopted for observing the discharges was as follows :—

Water was admitted into the pressure tank by the channel, *a*, *e*, *Plate* 29, until the water was brought to a level in both reservoirs as shown in the section, the surplus flowing off at *c* and *d*. The supply was then cut off at *a*, and when the water was at rest (having, of course, one connecting pipe, *f*, open), the floating gauges figured in *Plate* 29, were placed exactly vertical, one in the pressure tank, the other in the reservoir R. The wires of both were then adjusted to read alike.

All the orifices, *f f f*, were then securely closed at *s s s*, with the exception of that, to be observed.

Water was then again admitted into the pressure tank in excess of the probable discharge to be observed, and the long sleepers forming the movable waste-weir at *c* raised or lowered until the reading of the gauge in the pressure tank was higher than that in the outer reservoir by the amount of head required.

The head thus measured was the height of the surface of the water in the pressure tank above that in the reservoir R.

As soon as equilibrium was established, the reading of a third gauge in the large tank was noted, the time taken, and the gauges in the pressure tank and reservoir, which could be both seen by the observer at once, carefully watched to see that the head did not vary during the experiment.

If the head showed a tendency to increase, a small obstruction placed in the channel at *a* was sufficient to correct it; if to decrease, a brick or two on the sleeper *c*, over which the thin film of over-plus water was flowing, at once brought the weir up to the reading required.

After an interval of about two hours, the reading of the gauge in the large tank was again noted, time taken, and the experiment repeated.

As the tank was a large one for the purpose, a more sensitive gauge than that figured in *Plate* 30, was also employed as a check.

On one side of the tank, on a step 140 feet long, an incline was made,

having a height of 1·1 feet, the inclined face was graduated each 10 feet, thus representing a vertical rise of 0·1, and the foot and tenths 0·01 and 0·001 foot. The steady flow of water up this incline during an experiment was very satisfactory.

When that portion or stratum of the tank, into which the water was discharged by the pipes, became filled, the sluice at D, *Plate* 28, was opened, and the water ran off to the pond outside

The orifices experimented on consisted of cylindrical tiles of well-burned clay unglazed, each 1·4 feet long, joined with a butt joint, having a collar cemented over the joint 3 inches wide.

Besides these a rectangular wooden-pipe, 1·3 feet × 0·7 foot inside measurement, having a frame or diaphragm 1 inch thick, inserted in it 0·9 foot × 0·4 foot inside measurement, representing the ordinary temporary " mogah, " or private water-course head now in use on the Baree Doab Canal.

It will be observed that these experiments were made with both ends of the pipes submerged, such being the usual condition of water-course heads on this canal.

The water was the usually heavily silted water supplied by the Baree Doab Canal; the actual percentage of solid matter was not observed; it varied from day to day.

When the actual discharges of each pipe under various heads had been observed, the experiments on irrigation were commenced

The same description of pipes made by the same machine were inserted in the rajbuha bank, the head of pressure being observed in the same way as for the discharges above described

The time required to gave a thorough watering to a field was thus determined·—

No one watering to any standing crop (save rice) requires so much water as the first given on the fallow land to saturate it for ploughing.

Fallow lands, therefore, of various qualities were selected to experiment on, and a Committee of villagers was always present to decide when the fields were properly irrigated.

Time was taken when the water reached the field, and when the Natives judged the irrigation completed.

No water was allowed to enter the field until the head on the pipe had become perfectly stable. When this had been effected, a handful of chop-

PLATE XXIII.

PLAN OF CHEVINDA KHAL AND TANK.

A

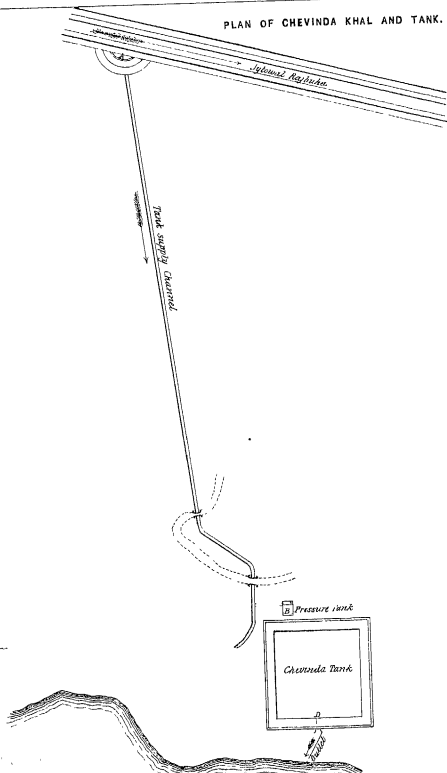
Jytowal Rajbuha

Tank supply Channel

B Pressure Tank

Chevinda Tank

D

Outlet

ped straw thrown in the water-course indicated when the water issued with the required head had reached the field, the escape in which the water had been running to waste was then closed, and the water turned into the field.

The same method was adopted for the observations of irrigation from wells and jhullars

The actual discharge of these raising machines was somewhat difficult to determine with any accuracy without going to a greater expense than seemed necessary. Where a well had a cistern (for cattle watering) attached to it, it was used as a measure, and the discharge observed with facility and accuracy. But when this was not obtainable, the discharge was computed by weighing the water brought up by a certain number of the well-buckets (tinds) taking the average, counting the total number of sound buckets on the rope, and noting the number of minutes expended in a revolution, repeating the last several times, and taking a mean.

Checked by a cistern in one instance, the result showed very fair accuracy.

I trust the above detailed description of the way in which these experiments were conducted will not be thought superfluous. It is true that such details are frequently omitted in the record of similar experiments, but it appears to me that the bare results of experiments are well nigh useless to the practical Engineer when the conditions under which they were made are not very exactly described

A table of the discharges observed is given in Appendix A., and in Appendix B. is shown the result of the irrigation experiments.

The experiments on what was intended to be a 3-inch pipe, were made with the view of demonstrating whether anything smaller than a 0·4 feet pipe could, with an average head, discharge as much as a jhullar or well. Had it done so, it might have been expedient to use them as a standard for issue to gardens. Comparing the discharge of No. VIII. Appendix A., with that of No. XXXIX. and XL., Appendix B., it will be seen that, with a head of 0·4 feet (the greatest head that can be depended on in a rajbuha on this canal), the discharge of the 3-inch pipe is about half that of an ordinary jhullar.

For agriculture, it is therefore (in my opinion) too small, and the economy obtained by using it for gardens would be more than counterbalanced by having two standard sizes of issuing pipes.

The experiments with the 0·4 feet pipe show that, with a head of 0·4,

the discharge with the 0 4 feet pipe is about 43 per cent. more than that of the best jhullar observed, No XXIV, Appendix B.

The 0·18 feet pipes were intended to be 0·5 feet diameter, but the shrinkage of the clay during firing being greater than was anticipated, their actual measurement was found to be 0·18 foot

They discharged as nearly as possible half a cubic foot per second with a head of 0·4 foot,—*vide* Nos II. and XXXVI., Appendix A.,—and this, which is more than double that of a good jhullar, is, I think, too large for ordinary service for small farms, to the requirement of which, the standard size pipe or outlet should be adapted, inasmuch as two, three, or four of a smaller sized pipe could be granted where the demand appeared to require a larger discharge.

As the group of fields belonging to one man or one family in the districts affected by this canal are generally considerably less than 50 acres, to fix on a sized outlet larger than is necessary for the irrigation of these would inevitably lead to great waste of water.

To judge of the proportional discharge of additional pipes that might be granted in one head for a large farm, two 0·5 feet pipes were laid close together, side by side, and simultaneously opened. Their united discharge, as shown in Appendix A., was.—

Head.	0·5 feet, double.	0 5 feet, single.	Proportion of double to single
2	81	0 31	2 61
·4	1·12	0 50	2 22
·6	1·43	0 59	2·42
			3)7 25
		Average,	2·42

Average, 2·42, say nearly $2\frac{1}{2}$ times that of a single pipe.

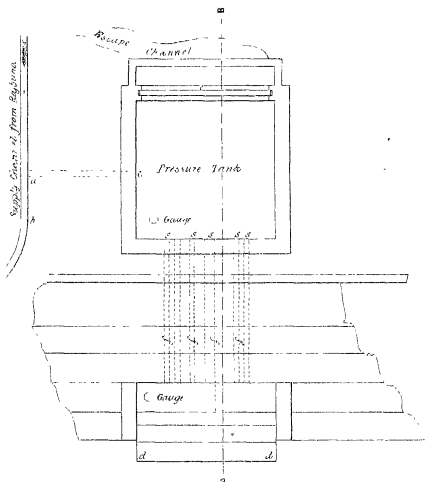
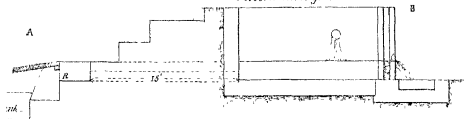
In granting additional pipes to a head, this should be borne in mind.

The result appears at first sight anomalous, but I think may be accounted for by the larger aggregate opening causing a higher velocity of approach. D'Aubuisson's experiments show a small increase.

The object of the experiments on the "Mogah" was to determine the

PLAN OF PRESSURE TANK.

Showing position of Gauges.

Scale, $\frac{3}{250}$

actual discharge of an outlet of whose irrigating powers we have abundant statistics on the Baree Doab Canal.

Appendix B., is intended to exhibit clearly—

1stly.—The duty that may be expected from each description of outlet.

2ndly.—The actual volume of water required to thoroughly saturate an acre of various descriptions of soil.

3rdly.—The time each outlet would expend in watering an acre.

In considering the power or duty of an irrigation head, it is obviously necessary to determine beforehand the duration of its flow.

After an experience of some seven years on a great variety of soils, and during some remarkably dry seasons, I may be allowed to express my opinion that, on this canal, no Officer is making the utmost of the water whose outlets are allowed to flow more frequently than one day in four; and, as it is necessary to assume some duration, I shall, in the following remarks, base the calculation on the supposition that a private water-course flows eight days (of 24 hours) in the month.

The area cultivated round a good jhullar may be safely taken as an average sample of the size of a farm owned by one man or one family. It is a more constant quantity than the arable round a well, as the circumstances of the latter must always present infinite variety.

The mean area of 50 jhullar farms actually measured was 52 acres, say, 22 acres of khureef, and 30 acres of rubbee harvest.

The averages in Appendix B. show that an average depth of 0·24 on the whole surface represents a thorough watering on average soil (in sandy land it is as much as 0·31), and 43,560 × 0·24 = 10,454 cubic feet as the volume required for 1 acre. Actually the average is (excluding the sand) 0·21 and 9,148 cubic feet, but it will be safer to use the larger number.

Taking a single holding or farm to be 52 acres, we see that with a 0·4-feet pipe working under a head of 0·4 discharging (*vide* Appendix A.) ·3323 cubic feet per second, with such an outlet a man would require 8 days to prepare his 22 acres of khureef for ploughing, and nearly 11 days for the 30 acres of rubbee ploughing. The best season for this operation lasts about six weeks or 1½ months, he would have at least 8 + 4 days (*vide* above) of constant flow from the canal, and would, therefore, be able to effect his irrigation from a single pipe easily for the khureef, and with economy for the rubbee

From this I infer that such a pipe is well suited for our requirements, as a minimum standard outlet.

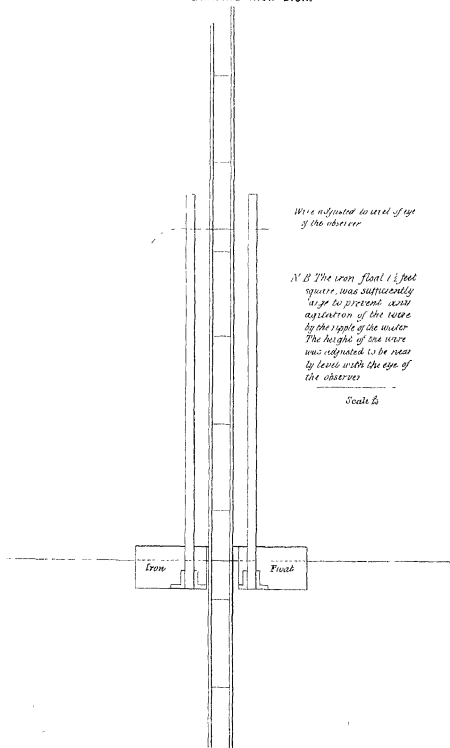
It may be objected that during seasons of drought so small an orifice, irrigating only 2·7 acres per day of 24 hours, would be incapable of securing 20 to 30 acres of standing crops, but it must be remembered that (excluding rice) no standing crop requires more than half of the quantity of water per acre that is necessary to saturate the ground for ploughing, the standing crops would, therefore, be watered at the rate of 5·4 acres per day.

The owner of such an outlet would be able to secure as much crop with his water flowing once in four days as his neighbour with a 22 feet well, working his cattle night and day, the proportional discharge being as 33 to 10 (*vide* experiments, Nos. V. and XX.)

The experiments, both on discharge and irrigation were too few to render this report as complete as I should wish. I can only say we found the greatest difficulty in finding spare time from our current work to conduct them, and that we were anxious to make sure of a few very carefully observed experiments rather than a larger number conducted more hastily.

And to obtain accurate results an expenditure of time apparently disproportionate to the amount of work actually recorded seems essential if the observer insists on seeing and doing everything himself. After a long day's work in the field, watching an irrigation experiment, it often occurs that some blunder or accident renders the whole day's work not, perhaps, wrong, but doubtful, and therefore, worthless.

At Appendix C. there are given a few deductions based on these experiments, which may be found interesting, but would needlessly lengthen this report.

ELEVATION OF GAUGE AND GUIDES AND SECTION THROUGH FLOATING IRON DISH.
Wire adjusted to level of eye of the observer
N B The iron float 1½ feet square, was sufficiently large to prevent any agitation of the wire by the ripple of the water The height of the wire was adjusted to be nearly level with the eye of the observer
Scale 1/10
Iron
Float

APPENDIX A.

Mean results of experiments of the discharge of various forms of irrigation outlets

N B—The cylindrical forms are earthen-pipes described in the report The rectangular orifices are the inside dimensions of a frame of wood 0 1 thick, fixed in a trough or box forming a diaphragm

Serial numbers of experiments in Field-book	Diameter of orifice	Head of pressure	Theoretical discharge $a\sqrt{2gh}$	Actual discharge observed, mean of experiments	Remarks.
			c ft per second	c. ft per second	
VII, ...	0·285	0·2	0·2289	0·0570	This size of pipe was not used in irrigation experiments, its discharge obviously too small
VIII, ...	0·285	0·4	0·3238	0·0732	
IX, ...	0·285	0·6	0·3966	0·1083	
VI, XXXVIII,	0·4	0·2	0·4510	0·2318	
V., LII, LIII, ..	0·4	0·4	0·6377	0·3323	
IV, XXXIII., ..	0·4	0·6	0·7811	0·4137	
I, ...	0·48	0·2	0·6494	0·3130	
II, XXXVI., ...	0·48	0·4	0·9184	0·5003	
XXIII., ...	0·48	0·6	1·3141	0·5981	
XIV., ..	·5 + ·5	0·2	1·4093	0·8131	Two ·5 pipes set close together.
XIII, XXXII.,..	·5 + ·5	0·4	2·005	1·1268	
XV, ...	·5 + ·5	0·6	2·141	1·435	
XXVII, X., ...	·9 ·4 □	0·2	1·306	0·801	The size of the diaphragm used for irrigation, *vide* XXV. and XXVI., was ·99 × ·12, discharge of which is computed from this.
XI, XXXV., ...	·9 ·4 □	0·4	1·847	1·114	
XXXI., ...	·9 ·4 □	0·5	2·065	1·430	

APPENDIX B.

Experiments of Irrigation on various soils.

Number of experiments in Field-book.	Orifice.	Head of pressure.	Discharge in cubic feet per second	Volume of water required for one acre	Representing a depth over the whole surface	Time required for our watering of one acre	Remarks.
		Feet.				*H* *M*	*Sandy land*
XVII.,	·9 ·4 □	0·2	0·801	12,480	·29	1 20	These experiments were made on very light sandy soil the fields being 2,700 feet from the rajbaha, time being taken from the time the water reached the field; loss by absorption in the long and sandy water-course is not included
XVIII.,	·9 ·4 □	0·4	1·114	14,304	·33	3 34	
XIX.,	○ 4′	0·2	0·23	12,851	0·30	15 24	
XXI.,	○ 4′	0·4	0·33	13,319	0·31	11 8	
XXII.,	○ 4′	0·6	0·41	14,595	0·33	9 48	
Average, ...	..	..	..	13,509	0·31	..	
							Ordinary Loamy soil.
XXV.,	·99 ·42 □	0·4	1·28	10,291	0·24	2 14	
XXVIII.,	○ 4′	0·4	0·33	9,057	0·21	7 34	
XXIX.,	○ 5′	0·4	0·5	6,870	0·157	3 49	
Average, ...	..	..	..	8,739	0·20	..	
							" Rolhe" land or heavy clay soil usually found in Drainage Channels
XXVI.,	·99 ·42 □	0·4	1·28	13,977	0·32	3 2	A parched clayed field with wide fissures caused by the shrinking of the clay

								Land representing the average soil found on the high land between Ravee and Sutlej "bar"
XLIII.,	○·5′	0·4	0·5	5,943	0·14	3	18	Field said by the owner to be thoroughly watered, but I considered it not half saturated.
Average, ...	..	..	..	9,960	0·23	..		
XLII.,	○ 5	0·5	0·56	9,778	0·224	4	51	
XLIII.,	○ 5	0·2	0·313	8,072	0·18	7	10	
XLIV.,	·4□·9	0·5	1·24	9,374	·215	2	6	
XLV.,	·4□·9	0·2	0·801	9,804	·225	3	24	
Average, .. .		.	..	9,257	0·21	..		

Irrigation by wells and jhullars on various descriptions of soil.

XVI.,	8′	Jhullar.	0·07	10,090	0·23	44	0	Soil ordinary loam, 120 feet distant, the raising gear in bad order (not worse than usual), it was stopped for repairs for 2½ hours out of the whole interval, but this was not deducted from the interval, as practically it would be impossible to keep it working 44 hours worked by one bullock
XXIV.,	4′	Do.	0·23	7,096	0·16	8	41	Soil, ordinary loam, close to the jhullar Apparatus in very good order; two bullocks
XXXIX.,	16′	Do.	0·13	13,311	0·30	27	37	Soil, recent river deposit, distant 6,800 feet, jhullar in good order, two bullocks
XL.,	16′	Do.	0·14	20,855	0·47	39	35	Soil, light river deposit, distant from jhullar 1 400 feet, rather over-watered in my opinion.

Irrigation by wells and jhullurs on various descriptions of soil.—(Continued).

Number of experiments in Field-book.	Orifice	Head of pressure	Discharge in cubic feet per second.	Volume of water required for one acre	Representing a depth over the whole surface	Time required for our watering of one acre.	Remarks.
	Lift.					M Sec	
XX,	22'	Well.	0·10	10,080	0 23	26 45	Ordinary loam distant 225 feet, well gear good, driven rather fast, a rather light watering
XLVII,	51'	Do.	0 21	.	..	.	No irrigation observed from this well, which was situated on the extreme limit of well irrigation in the "bar," and only used for irrigating a small garden patch, chiefly used for drinking
Average, ..	..	..	..	..	0 28	..	

APPENDIX C

The accompanying report gives data of the observed quantity of water required for irrigation

It will be interesting to calculate the value of the water thus used based on those data and in the figures given in the Revenue Report of the Irrigation Department, Punjab, for 1867-68

In the Revenue Report quoted, the Capital Account of the Baree Doab Canal is given up to 1st April, 1868, as Rs, 1,16,25,792, and the current expenditure during the year as—

	RS	
Direction, ...	30,826	
Establishment, ...	1,56,492	
Repairs, ...	2,17,783	4,05,101

The interest on the Capital for one year amounts, at 7 per cent., to Rs. 8,13,805, consequently the sum of these two last, amounting to Rs. 12,18,906, represents the cost of the water issued by the State during the year.

This sum has to be divided in equal parts on the two harvests, khureef and rubbee, or $\frac{1218906}{2} = 6{,}09{,}453$ for each; for the rubbee there are 182 days, in the khureef, 183. For the rubbee the average constant discharge was 959 9 cubic feet per second of water utilized, and $\frac{959\ 9 \times 3600 \times 24 \times 182}{\text{Rs}\ 6{,}09{,}453}$ $= 24{,}767$ cubic feet per Re. 1, and for the khureef the quantity utilized was 1782 1 cubic feet per second, and $\frac{1782\ 1 \times 3600 \times 24 \times 183}{6{,}09{,}453} = 46{,}234$ cubic feet per Re 1

For comparison of this the actual cost to the State, with the new revised rates now demanded, it will be sufficient to consider the two principal crops of each harvest, viz., wheat and rice

Wheat, in a dry season, requires five waterings. From the averages of the observations 10,454 cubic feet may be taken as the average quantity expended in watering thoroughly an acre of ground for ploughing, and for a standing crop 8,000 cubic feet would be ample; therefore the acre of wheat would require—

	Cubic feet	
For ploughing, ...	10,500	
Four waterings, at Rs. 8,000 cubic feet, ..	32,000	42,500

and 42,500 cubic feet at 24,767 cubic feet per rupee, would have cost the State Rs. 1-12-5 per acre; the rate now charged is—

	RS	A		
Water-rate, ..	2	8		
Water advantage rate,	1	2	3	10

Rice requires ten waterings, but a watering for rice, whether for ploughing or for a standing crop, has a very different meaning to that applied to any other crop. We have seen that to saturate the ground thoroughly for ploughing requires on average soil a depth of 0·24 feet to be thrown on the ground, *i e*, a quantity representing that depth were the soil impermeable, and with this quantity the surface of the ground is free of water in an hour or two, but, for rice, the irrigation is continued until some 6 inches of water remain on the surface of the heavy clay in which this grain flourishes. Nine inches depth on an acre represents 32,670 cubic feet, and ten such waterings would expend 3,26,700 cubic feet, and this divided by the khureef rate $\frac{326700}{46234}$ = Rs. 7-1; the rate now levied on this crop is

	RS.	A		
Water-tax, ..	4	12		
Water advantage rate,	1	2	5	14

Taking the figures for the whole canal, again quoting the same report, it appears that 1,46,000 acres were irrigated during the rubbee by flow (10,000 acres by raised irrigation may be omitted). With the volume above noted, divided by the acreage in feet, we obtain a depth over the whole crop $\frac{959 \cdot 9 \times 3600 \times 24 \times 182}{146000 \times 43560} = 2 \cdot 37$, and for the khureef, acreage of which was 1,04,000 $\frac{1782 \cdot 1 \times 3600 \times 24 \times 183}{104000 \times 43560} = 6 \cdot 219$

Had the whole of rubbee harvest consisted of wheat and barley (and its proportion was more than 5 acres to 1 of all other crops) the depth should have been $\frac{42500}{43560} = 0 \ 975$

Had the whole of the khureef been rice and cheena, the two being actually in area as 4 to 1 of all other crops, the depth should have been $\frac{326700}{43560} = 7 \cdot 5$.

From this it would appear there was a greater waste of water than can be accounted for by evaporation of water in channels during the rubbee; while the actual expenditure on the khureef is so near that of the calculated, especially when allowance is made for the crops, other than rice taking less water, that it can only be explained by the usual rain-fall, which of course relieves the canal greatly for a few weeks (during the harvest referred to 22 inches fell in Umritsur).

TABULAR STATEMENT of Agricultural Statistics compiled from information furnished by Deputy Commissioners in the Punjab

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
District Crop.	Mode of Irrigation.	CHARGES					RETURNS				Total value	Profit.	Rain-fall.	No. of waterings	Volume of water	No. of ploughings.	Depth to surface springs.	
		Cultivation.	Irrigation	Landlord's rent	Government assessment	Total	GRAIN Quantity	GRAIN Value.	STRAW Quantity.	STRAW Value.								
Goorgaon		RS	RS	RS	RS.	RS.	MDS	RS		RS.	RS	RS.	Inches. Year		Cubic ft.		Feet.	
Wheat, ..	Well	7 28	13 14	5 0	...	25 42	22	27 5	27 5	5 5	33 00	7 78	...	5	...	5	50	
Barley, ..	,,	7 28	10 55	5 0	..	22 83	26	26	26	5 21	31 21	8 38	..	4	...	5	50	
Gram, ..	Nil	6 64	..	3 0	..	9 64	15	15	15	3 77	18 77	9 13	26	...	...	3		
Barley & gram,	,,	8 00	...	3 0	...	11 00	17	17	20	4 00	21 00	10 00	26	.	..	5		
Jowar, ..	,,	6 17	...	3 0	...	9 17	12	12	24	4 00	16 00	6 83	26	...	...	3		
Bajra, ...	,,	5 46	...	3·0	...	8 46	11	12 08	11 66	1 16	13 24	4 78	26	...	...	3		
Cotton, ..	,,	7 375	.	3 0	..	10 38	7	21	.	.	21 00	10 62	26	.	...	4		
Wheat, ...	Well	7 25	12·00	5 0	..	24 25	23	27 5	25	5 00	32 50	8 25	...	4	...	5	51	
Barley, ..	,,	7 00	9 00	5·0	..	21 00	25	25	25	5 00	30 00	9 00	...	3	...	5	51	
Wheat, ..	Jheel	7 25	3 00	5 0	...	15 25	16	20	20	4 00	24 00	8 75	..	4	..	2		
Barley, ...	,,	7 25	3 00	5 0	...	15 25	20	20	20	4 00	24 00	8 75	..	4	...	2		
Gram, ...	Nil	6 00	..	3 0	..	9 00	15	15	15	3 75	18 75	9 75	23 to 35	...	..	2		
Jowar, ..	,,	6 75	..	3 0	...	9 75	12	12	24	4 00	16 00	6 25	23 to 35	.	..	3		
Bajra, ...	,,	6 5	...	3 0	...	9 5	12	13 71	12	1 17	14 88	7 38	23 to 35	...	...	3		
Cotton, ...	,,	8·375	...	3 0	...	11 375	8	24	..	..	24·00	12 625	23 to 35	...	...	4		
Montgomery													Rubbee					
Wheat, ..	Well	8·0	...	...	1·50	9 50	20	16	..	.	16 00	6 50	1 31	14	1,48,958	..	37	

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
District crops.	Mode of Irrigation	CHARGES.					RETURNS				Total value	Profit	Rain-fall.	No of waterings	Volume of water	No of ploughings	Depth to surface springs	
		Cultivation.	Irrigation	Landlord's rent	Government assessment	Total	GRAIN		STRAW									
							Quantity	Value.	Quantity	Value								
		RS	RS	RS	RS.	RS	MDS	RS		RS	RS	RS.	Inches. Year		Cubic ft		Feet	
Barley, ...	Well	8 0	...	...	1 50	9 50	24	16	..	..	16 00	6 50	2 33	10	1,32,343	.	26 2	
Kungnee, ...	"	7 0	...	..	1 50	8 50	24	14	...	..	14 00	6 50	3 96	9	61,?95		41	
Cheena, ...	"	7 0	...	...	1 50	8 50	24	14	...	...	14 00	5 5	3 19	12	89,159		41	
Cotton, ...	"	6 0	...	...	1 50	7 50	8	12	..	..	12 00	4 5	5 84	24	2,58,020	.	37	
Sealkote.																		
Wheat, ...	"	...	..	...	...	...	15 4	23 09	22 74	5 62	28 71	...	..	.	64,011	.	.	
" ...	Nil	..	.	...	..		7 39	11 7	15 09	3 75	14 82	.	..		...			
" ...	Well	10 80	3 52		3 00	17 32	13 0	19 5	10	2 5	22 0	4 68	...	4	. .	10	45	
Barley, ...	"	6 18	2 64	...	3 00	11 82	16 0	16 0	10	2 5	18 5	6 68	...	3	..	6		
Sugar-cane, ..	"	28 18	10 56	...	3 00	41 74	20 0	50 0	..	. .	50 0	8 26	.	12	...	17		
												Loss						
Cotton, ..	"	10 76	4 4	...	3 00	18 16	1 5	18 0	...	..	18 0	0 16	. .	5	...	7		
Maize, ...	"	6 08	3 52	...	3 00	12 60	18	22 5	..	. .	22 5	9 9	...	4	...	6		
Churree, ...	"	5 29	2 64	...	3 00	10 93	..	10 93	. .	.	10 93	0 0		3	..	3		
Flax, ..	"	9 80	3 52	...	3 00	16 32	10	25	...	...	25 00	8 68	. .	4	...	10		
Tobacco, ...	"	15 44	12 32	...	3 00	30 76	16	48	.	...	48 00	17 24	...	14	...	8		
Maize, ...	Nil	9 72	...	...	1 28	11·0	12	15		..	15 00	4 00	...	...	...	6		
Môth, ...	"	8 25	...	...	1 25	9 50	6	7 5	6	2 0	9 50	0 0	...	...	...	5		

											Loss						
Cotton, ...	,,	13 72	...	...	1 28	15 00	1	12	...	..	12 0	3 00	...	...	...	6		
Churree, ...	,,	9 96	...	...	1 25	11 21	..	16	..	..	16 0	4 79	..	...	...	6		
Wheat, ..	,,	14 30	...	...	1 25	15 55	10	15 0	10	2 5	17 50	1 95	...	...	...	8		
Barley, .	,,	13 80	...	...	1 20	15 00	12	12	16	4 0	16 00	1 0	...	..	...	8		
Gram, ...	,,	9 84	...	.	1 20	11 04	8	12	6	2 0	14 00	2 96	.	...	...	6		
Lahore													Year					
Wheat, .	Canal	12 756	...	...	...	12 756	9	12	24	4 0	16 00	3 244	49	4	59,241	...		Quantity of water exclusive of rain
Rice, ..	Canal	16 75	...	...	...	16 75	14	18 62	16	2 0	20 62	3 87	...	12	2,61 360	...		Quantity of water uncertain
Cotton, ..	,,	10 50	..	...	..	10 50	4	12 30	..	...	12 30	1 80	...	5	74,050			
Wheat, ..	Well	17 00	...	...	..	17 0	12	20 50	.	...	12 50	3 50	...	4	59,241	..	30 to 60	
												Loss						
Rice, ..	,,	19 18	...	...	..	19 18	14	17 50	..	1 0	18 50	0 68						
Cotton,	,,	7 12	...	...	.	7 12	5	12 50	..		12 50	5 38						
Tobacco, .	,,	35 0	..	...	...	35 0	10	40 0		..	40 0	5 0	...	32	3,48,480			
Maize, ...	,,	12 0	...	...	..	12 0	8 65	13 50	..	..	13 50	15	.	16 in 15 days	88,860			
Sugar-cane, .	,,	42 25	..	..	..	42 25	4 37	45 12	...		45 12	2 87	...	9	1,64,455			
Barley & gram,	Nil	7 75	...	.	..	7 75	3 32	10 18	..	.	10 18	2 43						
Môth, ..	,,	4 81	.	.	..	4 81	3 32	6 94	..	..	6 94	2 13						
Jowar, ...	,,	5 06	.		..	5 06	4 0	7 31	16	...	7 31	2 25						
Mash, ..	,,	6 00	...	..	..	6 00	3 0	6 94	6		6 94	0 94						
Wheat, ..	Sylaba	8 94	..	...	...	8 94	6 0	8 0	20	2 50	10 50	1 56						
Goordaspoor																		*Pergunnah.*
Wheat, ..	Canal	14 06	..	12 26	.	26 32	23 20	33·14	..	..	33 14	6 82	..	..	..	..	..	Goordaspoor.
,, ..	,,	7 30	.	1 39	.	8 69	6 57	9 38	..	..	9 38	0 69	..	..	..	.	..	Puthankote.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
		Charges					Returns.											
							Grain		Straw.									
District Crop	Mode of irrigation.	Cultivation.	Irrigation.	Landlord's rent	Government assessment.	Total	Quantity	Value	Quantity	Value.	Total value.	Profit.	Rain-fall.	No of waterings	Volume of water.	No of ploughings	Depth to surface springs.	
		RS	RS	RS.	RS	RS	MDS	RS		RS	RS.	RS.	Inches Year		Cubic ft		Feet	*Pergunnah.*
Sugar-cane..	Canal	27 94	..	9 75	..	37 69	22 8	57 0	..	..	57 00	19 31	..	..	..	.	..	Goordaspoor.
" ..	"	12 77	..	4 56	..	17 33	9 6	21 22	..	..	21 32	3 99	..	..	..	.	..	Puthankote.
Cotton, ..	"	15 0	..	2 60	.	17 60	6 0	22·5	..	..	22 50	4 90	..	..	..	..	..	Goordaspoor
"	"	7 53	..	0 36	..	7 89	3 0	10 0	..	..	10 00	2 11	..	..	..	.	.	Puthankote
Rice, ...	"	14 06	..	7 09	..	21 15	22 8	22 81	..	..	22 81	1 66	..	.	.	..	..	Goordaspoor.
"	"	8 84	..	1 64	..	10 48	14 5	12 08	..	.	12 08	1 60	..	..	..	..	..	Puthankote
Wheat, ..	Well	13·17	..	10 24	..	22 41	20 8	29 72	..	..	29 72	6 31	..	..	..	.	..	Goordaspoor
"	"	9 66	..	..	..	9 66	12 55	20 84	..	.	20 84	11 78	..	..	..	..	..	Shukurgurh.
"	"	7 22	..	14 10	..	21 32	20	33 33	..	..	33 33	12 01	..	..	..	.	.	Ditto
Sugar-cane,	"	22 94	..	..	..	22 94	21 2	53 00	..	..	53 00	30 06	..	..	..	..	..	Ditto
"	"	19 59	..	18 73	..	38·32	19 2	43 00	..	..	48 08	9 76	..	..	..	..	..	Ditto
Wheat, ..	Nil	11 66	..	10 65	..	22 31	19 27	27 84	..	..	27 84	5 53	..	.	..	..	..	Goordaspoor.
"	"	6 06	..		..	6·06	11 20	18 66	..	..	18 66	12 60	..	..	..	..	..	Shakurgurh
"	"	6 25	..	13 40	..	19 65	19 20	32 00	..	..	32 00	12 53	..	.	..	..	..	Ditto
"	"	4 74	..	..	1 91	6 65	5 1	7 28	..	.	7 28	0 63	..	..	..	.	.	Puthankote.
Barley, ...	"	11 42	..	..	3 95	15 37	15 8	15 37	..	..	15 37	0 00	..	..	..	.	.	Goordaspoor.
Cotton, ..	"	12 60	..	..	1 59	14 19	4 0	15 0	..	..	15 0	0 81	..	.	..	..	..	Ditto
Sugar-cane, ..	"	17 93	..	..	..	17·93	19 4	48 5	..	..	48 5	30 57	..	..	..	.	..	Shukurgurh.
"	"	16·56	..	..	19 25	35 81	19 2	48 0	..	..	48 0	12 19	..	..	..	..	..	Ditto
"	"	8 52	..	..	3 92	12 44	6 4	14 21	..	..	14·21	1 77	..	..	..	..	..	Puthankote.
Oord, ...	"	11 66	..	..	9 26	20 92	7 7	24 75	..	..	24 75	3 83	..	..	..	..	..	Goordaspoor.
Maize, ...	"	11 66	..	..	8 29	19 95	16 0	22 81	..	.	22 81	2 86	..	..	..	..	..	Ditto
"	"	4·34	..	..	1 55	5 89	7 0	7·0	..	..	7 0	1 11	..	..	..	..	..	Puthankote.

Note by Major E. L. Earle, S.C., *Offg. Supdg. Engineer, Upper Baree Doab Circle.*

Dated 25th August, 1871.

The pipes experimented on were all 15 feet in length,—that being the average length of water-course heads,—and were of two kinds in section, cylindrical and rectangular. The former were of baked clay, ·285, ·4 and ·48 in diameter, intended for ·3, ·4 and ·5 pipes, and the latter of wood, with a diaphragm fixed in, having an orifice ·9 × ·4.

The discharge of these were observed under ·2, ·4 and ·6 heads of water, the heads being measured by the difference in level of the surface of the water on either side of the orifice which were submerged, such being generally the case with water-course outlets.

As the tank into which the discharge for ascertaining the quantity of water issued was a large one, each experiment was carried on for about two hours, and the depth of water discharged into the tank then measured off from a very much enlarged scale, as described in the report. Every care seems to have been taken to ensure as much accuracy as possible. The several experiments on discharge are shown in Appendix A.

With regard to the best size of pipe for water-course heads, Mr. Palmer considers that the ·3 pipe, discharging only ·0732 cubic feet per second, with a head of ·4, the greatest to be depended on in a rajbuha, or about half that of an ordinary jhullar, is too small for agricultural purposes. The ·4 pipe, discharging with the above head ·3323 cubic feet, or nearly half as much again as the best jhullar observed (·23 cubic feet per second), is the size Mr. Palmer recommends for general adoption. The ·5 pipe, which discharges nearly half cubic foot of water a second, or more than double that of the best jhullar, is too large.

For the quantity of water and the time required for irrigating land, Mr. Palmer made experiments on fallow land, selecting fallow land as more water is required to saturate it for ploughing than is required for watering standing crops.

The several experiments made for this purpose are given in Appendix B. From these the average depth of water to saturate the different kinds of soil experimented on was as follows:—

Sandy soil, ...	·37 cubic feet
Loamy „	·22 „

Heavy clay soil, ... ·28 cubic feet
Ordinary soil found on high land between Beas and Ravee Rivers, ... ·27 "

From these experiments, taking 3 feet as the depth of water required, to saturate land, and which is more than is necessary for any but a sandy soil, Mr. Palmer shows that an ordinary-sized farm of 52 acres obtained from actual measurement of 50 jhullar farms, consisting of, say, 22 acres of khureef and 30 acres of rubbee land, could be watered for ploughing from a ·1 pipe, the former in 10 days, and the latter in $13\frac{2}{3}$ days; and that as the season for ploughing lasts $1\frac{1}{2}$ months, if it be assumed that a water-course flows 8 days in the month, the former area could easily be prepared within the time required, and the latter with a little economy.

The time required to cover an acre of land as above is ·455 days, or at the rate of 2·2 acres per day For standing crops the rate may be taken at 4·4 acres, for these, with the exception of rice, do not require more than one-half as much water as is necessary for ploughing. This rate, even in a season of drought, would be sufficient to secure 20 or 30 acres of cultivation

In comparing the irrigating power of such an outlet with that of machines for raising water, Mr Palmer states that as much irrigation could be obtained with water flowing only once in 4 days as from a 22 feet well worked night and day As from experiment No XX, Appendix A., the discharge of the 22 feet well was ·10 cubic feet per second, the advantage in favor of the canal water-course does not appear to be quite so great

I quite agree with Mr. Palmer in thinking that the ·4 pipe is best suited for canal water-course heads. Where large areas of land had to be irrigated, and one such pipe would not suffice, two or more could be given to the same head. In cases of such heads, Mr. Palmer points out that the discharge from two pipes placed together is more than twice that from a single pipe; the discharge from double and single ·5 pipes experimented on being nearly as $2\frac{1}{2}$ to 1

These experiments, which are of much use in enabling some idea to be formed of the quantity of water requisite for irrigating a certain area of land, and thereby utilizing the water available to the greatest extent, have been carried out with much labor and care, and under great difficulties, for which Mr. Palmer and Captain Palmer deserve great credit.

No. XXXVI

EQUIVALENTS OF METRICAL WEIGHTS AND MEASURES.

THE following figures which are those that are finally adopted by the Standards' Commission, have been received from the Warden of Standards

The metre is the length of the French standard at temperature 32° Fahrenheit

The yard is the length of the English standard at temperature 62° Fahrenheit.

The metre, when compared to the yard, both having a temperature of 32° Fahrenheit, is 39 37079 inches. The metre at 32° Fahrenheit, compared with the yard at 62° Fahrenheit, is 39·382 inches, and this is henceforth to be considered the correct equivalent for use. This modification of the usually accepted figures leads to the following changes :—

		Old Equivalent		New Equivalent	
1 Kilometre	=	0 621382	Mile	0 62156	Mile.
1 Metre	=	1 093633	Yards.	1·09394	Yards.
		3 280899	Feet	3 28183	Feet.
		39 370720	Inches.	39·38200	Inches.
1 Mile	=	1609 315	Metres	1608 850	Metres.
1 Yard	=	0 91438	Metre.	0 91412	Metre.
1 Foot	=	0 30479	„	0 30470	„
1 Inch	=	0 02539954	„	0·2539231	„
1 Square Decimetre	=	15·50059	Square Inches.	15 50942	Square Inches.
1 Square Metre	=	1 19603	„ Yards	1·19671	„
		10 7643	„ Feet	10 77043	„
1 Are	=	119 60332	„ Yards.	119 67144	„
Hectare	=	2 47144	Acres.	2·47255	Acres.

		Old Equivalent.	New Equivalent.
1 Square inch	=	0·06451 Square Decimetre	0·0644765 Square decimetre
1 Square foot	=	0·092890 ,, Metre	0·092[illegible]161 ,, Metre
1 Square yard	=	0·836097 ,, ,,	0·83561 ,, ,,
1 Acre	=	0·40467 Hectare	0·40111 Hectare
1 Square mile	=	258·98911 Hectares.	258·8460 Hectares
1 Cubic Metre	= {	35·31658 Cubic Feet 1·30802 ,, Yards.	35·31675 Cubic Feet 1·30911 ,, Yards.
1 Cubic inch	=	16·38618 Cub. Centimetres.	16·37207 Cub. Centimetres
1 Cubic foot	=	28·315311 ,, Decimetres.	28·29087 ,, Decimetres
1 Cubic Yard	=	0·76451 ,, Metre	0·76385 ,, Metre
1 Litre	=	0·22024 Gallon.	0·22018 Gallon.
1 Gallon	=	4·54041 Litres.	4·54173 Litres

The kilogram remains unchanged, being 15432·34874 grains, or 2·204621 lbs. avoirdupois: 1,000 kilograms equal 0·984206 ton.

One pound avoirdupois equals 0·45359265 kilogram.

One ton equals 1016·04754 kilograms.

R. S.

INDIA OFFICE,
The 5th December, 1871.

No. XXXVII.

TABLES OF INDIAN CROPS.

By Capt. J. M. Heywood, R.E.

The data furnished in these Tables have been collected in connection with investigations on the duty of water in regard to Irrigation schemes.

The list of Bengal Crops has been revised by the Principal of the Indian Museum, at Calcutta, and the Superintendent of the Calcutta Botanical Gardens.

The list of Madras Crops was communicated by Dr. Hunter, of the Madras School of Art.

The list of the Bengal and North West Crops is incomplete, the deficiency in this respect can however, it is believed be easily supplied by numerous officers in those Provinces.

From Bombay no data have been collected.

	Description of crop.	Scientific name.	Bengal — When sown	Bengal — When cut	Madras — Native name of crop	Madras — When sown	Madras — When cut	North West — When sown	North West — When cut	Punjab — When sown	Punjab — When cut
CEREALS.	Wheat, ..	Triticum vulgare,	November	Febr and March	Godum-bay.	July	December	October.	March.	October & November	March and April
		Triticum durum,	,,	,,				,,	,,	,,	,,
	Oats, ..	Avena sativa,	,,	,,				,,	,,	,,	,,
	Barley, ..	Hordeum hexastichum	,,	,,				,,	,,	,,	,,
	Jowar (great millet),	Sorghum vulgare,	July.	October	Cholund	September	,,	June	October	,,	,,
	Bajra (spiked millet),	Penicillaria spicata,	,,	,,	Cumboo	April.	June	July	,,		
	Kangnee (Italian millet),	Pennisetum Italicum,	,,	,,	Tenney	September	January				
	Maize, ..	Zea mays,	April.	July.	Mucca cholum	July.	October	June	August & September		
	Cheena or Arzan, ..	Panicum miliaceum.	July.	October.	Chamay.	,,	January.				
	Damra, ..	Panicum frumentaceum,	,,	,,							
	Kalo debdhan, ..	Sorghum bicolor,	October	February							
	Aous, .	Oryza sativa,	May and June	Sept and October	Nelloo.	,,	February	,,	October	July.	Sept and October
	Aumon, ..	,,	June and July	Dec and January		,,	October.				
	Bora, ..	,,	February	April		January	April.				
FIBRES.	Sugar-cane, ..	Saccharum officinarum,	Febr. and March	Febr and March.	Tharoom-boo	May	January	March	December	Febr to April	Nov to February
	Cotton, ..	Gossypium herbaceum,	February	May.	Paratie.	,,	,,			April to June	January to February

Fibres.	Hemp, . . .	Cannabis sativa,	April	September	Gunja.	Any time	6 months			
	Jute, .	Corchorus capsularis,	„	August & September	Allecve-ray					
	Flax, . .	Linum usitatissimum,	February.	April		„	5 months	October	March and April.	
	Sun, hemp, . .	Crotalaria juncea,	April	August	Janupa nai.	August	March			
	Sanni patsan,	Hibiscus cannabinus,	July	November	Poolchie	„	„	June and July	October	
Pulses.	Mussoor, . .	Ervum lens,	October	February						
	Choto mussoor, .	Ervum hirsutum,	„	„						
	Múng, .	Phaseolus mungo, Phaseolus Max, W	February	April	Pucha pa yaroo	September	December			
	Oorud Pullay, .	Phaseolus Roxburghii	„	„						
	Arhar, . .	Cajanus indicus,	June	March	Thovaray	July	April.			
	Chunna, . .	Cicer arietinum,	October.	February	Kadalay	„	„	October & November	Febr and March	
	Buro chunna,	Vicia sativa,	„	„						
	Chural, Khesari, .	Lathyrus sativus,	„	„						
	Peas, muttur, .	Pisum arvense, W	„	„	Puttanie	September	December.			
	Choto muttur, .	Recina subquadratum,	„	„						
	Mooseree . . .									
	Sona moog, . .	Phaseolus aureus,	June	September	Ulandoo	July.	February	June and July.	October	
Pulses	Moth, . .	Phaseolus aconitifolius,			Toolka pyre	December	March			

	Description of crop	Scientific name.	Bengal.		Madras.			North West.		Punjab.	
			When sown.	When cut.	Native name of crop	When sown.	When cut	When sown.	When cut	When sown	When cut
Dyes.	Indigo, ..	Indigofera tinctoria,	Febr. and March	June and July.	Averie.	November	March				
	Safflower, ...	Carthamus tinctorius,	October.	February							
	Madder, ..	Rubia cordifolia,			Emboord chay root	October.	February,				
	Turmeric, ..	Curcuma longa,	June.	February & March.	Munjel	August.	„				
	Ginger, .. .	Zingiber officinale,	„	„	Injre	September	„	June.	September to Novr		
Oil Seeds.	Linseed oil, .. .	Linum usitatissimum,	February	April	Alleveray	Any time					
	Coriander, .	Coriandrum sativum,	December	February	Collamil-lie.	December	March.				
	Kam til, .	Guizotea abyssinica,	September	Feburary & March							
	Táramíra, ...	Sinapis eruca,									
	Shwet swisha, .	Eruca sativa,	October	„							
	Sesamum, Til or Tilli	Sesamum orientale	„	February	Yelloo	January	April				
	Mustard, ...	Sinapis nigra,	„	„	Kadaghoo	September	February				
	Rai (native mustard,)	Brassica campestris.	„	„							
	Castor oil, ..	Ricinus communis,	June.	Febr and March	Sillamu-nuk	August.	November				
	Shwet rai, ...	Sinapis glauca,	October.	„	Kadaghoo	September	February				
	Sarroo, ...	Brassica juncea,									
	Sursha, ...	Sinapis dichotoma,	„	„	Kadaghoo	„	„				

BOUS AND ISPICES	Poppy, ..	Papaver somniferum, L.,	November	March	Casa casa.	October	March.			
	Tobacco, ..	Nicotiana tabacum Nicotiana rustica,	September	February	Poghrielly	January	April			
DRUGS & SPICES,	Tookhum balangu, ..	Lallemantia Roylcana,								
	Pethá (Pumpkin),	Benincasia cerifera,	July	January						
GARDEN FRUITS, &c	Tarbuz (water-melon), ..	Citrullus vulgaris,	February.	April and May	Pitcha pullum	February	April.			
	Karbuza (melon), ..	Cucumis melo,	"	"	Molam.	April.	July			
	Khíra (cucumber),	Cucumis sativus,	April & May	July and September	Vellері.	"	"			
	Kakri (cucumber),	Cucumis utilissimus,	February	April and May.						
	Safed kudoo (squash)	Cucurbita maxima	January & February	"	Pusani.	July	December			
	Chikenda (snake gourd), .	Trichosanthes anguina,	April	August	Poodelum	,	"			
	Phulwul, ..	Trichosanthes dioeca,								
	Sirwa, ..	Anethum sirwa.	November	February	Satha cooppee	December	March			
	Methí, or methri,	Trigonella fœnumgræcum,	"	,	Koth averay	July	October			
	Cheenee badam, ..	Arachis hypogæa,	July	"						
	Gajar. carrot,	Daucus carota,	October.	January & February	Carrot kalung.	September	January			
	Singhara, .	Trapa bispinosa,		August to October						

J. M. HAYWOOD

No. XXXVIII.

FELLING TIMBER IN THE HIMALAYAS

[*Vide* Plates Nos XXXI, XXXII]

By George Pellew Paul, C E., *Timber Agent to the Contractors for the Delhi Railway.*

[Note by Editor.]

The following extracts are taken from an interesting book written (and published for private circulation) by an Engineer, who has devoted five years to felling trees, and launching logs from the pine forests of the Himalayas bordering on the river Sutlej Although many individuals have conducted similar operations in this country, scarcely any have as yet recorded and published their experience, giving the actual details of the work carried out by them. The record of failures and successes, of difficulties encountered and overcome, and of the varied details of foresters' work in the Himalaya, (or elsewhere,) would be useful, not only to forest conservancy officers, timber agents, &c.; but to the engineering profession at large, whose members are occasionally liable to have work of a similar nature devolving upon them in connection with road-making, bridge building, &c., in mountainous and wooded countries. The book from which these extracts are taken is far too large to be reproduced *in extenso* in this publication, nor indeed is all its matter exactly suited to the special scope of an Engineering Journal · but the portions selected will give a general idea of the nature and style of the work, and the insertion of this article in the "Professional Papers on Indian Engineering," may induce others familiar with the subject to furnish records of their experience of the Engineering operations connected with timber felling and transport

Introductory Remarks.—In 1865, stocks of deodar timber in the depots on the various rivers of the Punjab had become so scarce, and the principal sources (forests of the Chenab and Ravee rivers) from whence it had for many years previously been supplied, had been so much exhausted, that for fear of the utter annihilation of such forests, strict orders had been issued by the Government to stay further fellings, and as our requirements for sleepers especially, and wood generally, were on such a large scale, and as I saw no other prospect of obtaining anything approaching our wants, I was induced to suggest to the Firm the advisability of ourselves undertaking the cutting and launching of logs in some of the Himalayan forests bordering the Sutlej river, (provided we could obtain the sanction of Government) and floating them down to Phillour, close to which place the line of railway passed

Not until the early part of 1866 did an opportunity present itself for carrying out this idea, when (the late) Mr. M Ter Arratoon made us an offer of 8,000 Deodar trees situated in the Koonawar sub-division of Bussahir, of which by some means or other he had become possessed.

Preliminaries being arranged, I started from the plains in the beginning of May 1866, reaching the scene of my future labors towards the end of the month.

Locality of the Scene of Operations.—The forests in which I was permitted to fell—seven in number—viz, SAPNI, KOOMKOOMEE, KUNAI, JOOMPAN, PHINLA, JANEE and RAWNI, are situated in the sub-division of Rasgeemee, District of Koonawar, (quasi-independent) territory of Bussahir, in latitude 31° 30½′, longitude 78° 13′, distant about 130 miles from Simla, in an easterly direction, on the left hand side of the valley formed by the river Sutlej, which here careers along with mad impetuosity between two ranges of mountains, whose cloud-capped summits are mostly about fifteen thousand feet above the level of the sea, although some of these giants tower up to 18,000 and 21,000 feet, notably those of the Raldang Range, whose principal peak, called Kylass, reaches the latter height.

The region is rugged in the extreme, the culturable portion of the valley being not more than from seven to nine miles wide, and then only in patches where the nature of the hill sides allow of such a proceeding.

The principal features of the country are deep worn valleys, sometimes narrow, anon spreading out, always more or less rocky, divided by mighty spurs, and rapid torrents precipitous mountains, the tops of whose vast chains are veiled in everlasting snow, forming the watershed line of the innumerable streams which issue from their sides, and from whose drainage they are fed: inaccessible crags, and almost impenetrable forests of pines, oaks, and birches.

The only means of communication with the outer world was by the Hindoostan and Tibet road, whose average width of 7 feet only allowed mules being used as the method of transport, and even this road was not available for our purposes the whole way, as it quitted the left and crossed to the right bank of the river Sutlej at Wangtu, just twelve miles short of the scene of our operations. From that point there were no means of communication, but a hill track in every respect both bad and dangerous

Labor.—The State of Bussahir is very well populated, and there is no lack of labor, if it can only be induced to come forward for work; but the men, as a rule, are so thoroughly lazy, that it is only to obtain just sufficient to pay their taxes to the Rajah and Wuzeers that they come for employment.

However, as the timber was urgently required to prevent any delay in the opening of the railway, I had to make arrangements for importing laborers from the adjacent territories, and with the help of the "necessary advances" I was fairly successful.

These "foreign" laborers came from Kooloo, Kangra and Koteghur in British territory, and the (quasi) independant States of Mandee, Gurhwal, Chamba, as well as from the Chooara Division of Bussahir, all access to these places being across snowy passes. The men of Kooloo, Kangra and Chamba are a stalwart race, and in appearance a much more manly looking set of beings than the generality of the Hill races, although they too require the usual amount of driving to keep them at their tasks. They used to arrive in May, or as soon as the passes were open, and left again about the end of October, just before the passes were closed. The Bussahirees of the Koonawur, Pandra-Bis and Athara-Bis districts, used to work all the year round, as, in spite of snow and frost, operations (after the first season this was done) were carried on in winter, as well as summer, to enable timber to be launched as speedily as possible For weeks I

have worked in a foot of snow with the thermometer below freezing point at extricating logs from the forests and putting them into the river.

From personal observations of the different races I have had at sundry times in employment, I am inclined to look upon the Chamba men, and Koonawarees, as the most honest, while the people of Chooara and Gurhwal, particularly the latter, are the most arrant rascals I know.

Provisions.—The inhabitants of Koonawur grow but barely sufficient grain for their own consumption, and no supplies of food for my imported laborers were obtainable near the scene of operations; I had therefore to bring everything up from the lower hills, (principally from the British territory of Kooloo opposite Rampore), an average distance of 70 miles. It had all to be carried on the backs of mules, sheep or goats, as no other means of transit were available, and when I add that there were occasions when from 400 to 500 mouths (nearly a regiment) were dependent on me for their actual daily feeding, some idea of my anxieties on that score may be inferred. The least break down in the commissariat arrangements, and starvation stared them in the face, and their dispersion would be the inevitable result of such an occurrence. I took every precaution I could to guard against such a contingency, by endeavouring to accumulate a reserve, but for the first three seasons everything was consumed nearly simultaneously with its arrival, and I had great difficulty in laying up sufficient supplies for the winter months, during which period mules and such like beasts of burden cannot travel up into these regions.

The following tabular statement will show the annual consumption of provisions, from which some idea will be formed of the labor that this entailed upon me. Lalla Golab Sing, treasurer to the Hill Roads Division, Simla, was my principal grain contractor throughout, and I here bear testimony to the able manner in which he and his subordinates performed their work.

Abstract of Provisions consumed in 54 working months, or an average of 213 Maunds per month.

YEAR	Flour	Goor *	Rice	Dall †	Tobacco	Salt.	Ghee ‡	Red pepper	Soap	Oil.
	§ Mds	Mds	Mds.	Mds.	Mds	Mds.	Mds.	Mds	Mds	Mds
5 months, 1866	665	1¾	17	3	4	1½	1½	.	.	9
8 months, 1867	1,451	15	41	16	23	12	5	¾	¾	18
12 months, 1868	2,973	31½	214	42	11½	22½	26¼	1¾	¾	23¾
12 months, 1869	2,971	20	272½	32¾	8¼	28	33¼	1¾	2	20¾
12 months, 1870	1,304	11½	67¼	11½	4½	9¼	12¾	1⅓	1¼	22¼
5 months, 1871	814	½	13	15½	8¾	57½	21	2	⅛	,,
Total Mds.	10,271	80¼	624¾	120¾	60½	131¼	99¾	7½	4⅞	96¾

In issuing them the losses sustained from "tare and tret," rats, mice, robberies, &c., were—

		Per cent.	
Flour,	..	..	Not yet ascertained. Still in course of issue.
Goor,	..	40	Fermented greatly.
Rice,	..	..	Not yet ascertained. Still in course of issue.
Dall,	..	10	
Tobacco,	..	48½	A great portion became stale and unfit for use: thrown away.
Salt,	..	36	
Ghee,	..	9	
Red pepper,	..	..	Not yet ascertained. Still in course of issue.
Soap,	..	50	Greatly affected by rats.
Oil,	..	3	

The greater portion of the less occurred while the provisions were kept

* Unrefined product of the sugar-cane *(Saccharum officinarum)*.
† Split peas *(Phaseolus Mung*, and *P. Radiatus)*.
‡ Clarified butter.
§ 80 lbs. = 1 Maund.

in the native huts at Ooruee and elsewhere, and before our own stores were ready to receive them: since then our loss has been merely the difference between weighing in and out.

Rates of Wages in the Forests.—These throughout were high, but as the scene of my operations was so far away from any centre of labor, the dearness of imported provisions rendered it necessary to hold out a good inducement to obtain workmen, for, otherwise, it would not have been worth their while coming very far. But the wages are at least 25 per cent. higher than the Government need pay in future with regular work carried on in the manner proposed under the suggestions for the future working of these forests.

TABLE OF RATES.

	RS	A.	P.
Daily coolies, Men and Women, each, ...	0	4	0
„ Boys and Girls, „	2 to 3 ans.		
Jumping a mine, 18 inches deep (in stone), ...	0	5	0
Tamping clay, per coolie load, (generally sufficient for 22 mines,) ..	0	2	0
Jumping a mine, the men finding their own steel for pointing the jumpers, powder for blasting, clay for tamping, and firing the mine, ...	0	8	0
Powder charged to the men at per seer of 2 lbs., ...	1	0	0
Steel ditto, ditto, ...	0	12	0
Rolling and launching logs up to 12 feet in length, for each 1000 feet rolled, ...	0	8	0
12 feet to 18 feet in length, for each 1000 feet rolled, ...	0	10	0
18 „ 24 ditto, ditto, ...	0	12	0
Extricating, leading and launching sawn scantlings per 1000 lineal feet of road, (average for all sizes,)	0	1	0
Making carts, each, ...	0	7	0
„ a cart axle, ...	0	3	0
„ a pair of cart wheels, ...	0	4	0
„ a platform for cart, ...	0	0	6
„ a pair of cart wheels with iron tires, ...	0	4	6
Manufacturing unrefined pine oil, per maund, ...	1	8	0
Cart ropes, ¾" diameter, and about 15 feet in length, per maund, ..	5	0	0
(with an addition of 1 rupee per maund for bringing it from Pandra-Bis, where it was principally manufactured) One of the above ropes would lead 2½ pieces of scantlings of sizes.			
Making temporary clearing or slide in forest to pass the logs down, including removing stumps up to 15" in diameter, per 1000 lineal feet, ...	1	8	0
When the stumps are above that dimension, then for each one an additional sum of, ...	0	2	0
(These clearings varied from 10 feet to 30 feet in width).			

	RS.	A.	P.
Felling trees, each, ..	0	4	0
Clearing the branches, each tree, ..	0	2	0
Making logs, each, ..	0	1	0
Logging, with cross cut saw, each,	0	4	0
" axe, ..	0	2	0
Rough masonry in checkwalls per 100 cubic feet, ..	0	8	0
Filling in to ditto, 1000 " ..	2	8	0
Sawing scantlings 13 × 11 × 5½ each,	0	8	0
" " 13 × 11 × 11 " ..	1	0	0
" " 14 × 11 × 5½ " ..	1	0	0
" " 14 × 11 × 11 " ..	2	0	0
" " 24 × 11 × 5½ " ..	1	8	0
" " 24 × 11 × 11 " ..	3	0	0
" planks per 100 superficial feet, ..	1	0	0
" small scantlings, per cubic foot, ..	0	1	0
Erecting railing on mule road per 100 lineal feet, ..	5	0	0
Hire of a mule from Simla, carries 2½ maunds or 200 lbs., ..	9	0	0
" " " " one stage, ..	0	12	0
(Two pice additional, per stage, for mate's fee.)			
Hire of a coolie from Simla, ..	3	2	6
" one stage, ..	0	4	0
(Two pice additional, per stage, for mate's fee)			
Steel, per seer, ..	6 to 8 ans.		
Blasting powder, including carriage, per seer, ..	0	15	0
Iron, ..	5½ to 6 ans.		

PROVISIONS.

		RS.	A.	P.
Flour, per maund, ..		6	0	0
(Issued out at Rs 5 per maund),				
(Portions purchased at Rs. 3-8, 4, and 5, per maund)				
Goor (unrefined produce of sugar cane),	"	11	0	0
Rice, ..	"	7	0	0
Portions purchased at Rs. 5, and 6	"			
Dall, ..	"	6	10	8
Tobacco, ..	"	11	0	0
Portions issued at Rs. 10	"			
Salt, ..	"	10	0	0
Ghee (clarified butter), ..	"	32	0	0
Portions purchased at Rs. 24	"			
Masallas (red pepper and turmeric),	"	20	0	0
Soap, ..	"	20	0	0
Oil, ..	"	11	0	0
Portions issued at Rs. 13-5-4	"			

The greater number of my coolies were distant from their homes three to four days' journey, yet once a month they found it cheaper to leave

their work and wages, and travel to and from that distance to fetch their own provisions, instead of taking ours at eight seers per rupee.

	RS.	A	P.
Thus, say that a man worked regularly, he would receive for a month of 30 days, @ 4 annas, ...	7	8	0
His flour, if obtained from our stores, would cost him, ..	3	12	0
Profit Rs, ..	3	12	0
If he goes to his home to fetch it, he would lose at least 6 days' wages = Rs 1-8-0, this deducted from Rs. 7-8 0, leaves,	6	0	0
His flour would stand him at 20 seers per rupee, ...	1	8	0
Profit Rs, ..	4	8	0

So that although he loses 6 days of wages, yet is he better off by 12 annas at the end of the month by bringing his flour from his own house.

I endeavoured to introduce Mangold Wurzel (*Beta Campestris*) amongst the villagers as a beneficial crop for their cattle, to be stored for winter use; and although they fully appreciated the advantages to be derived from its cultivation, still the question, " what would be the tax on it as soon as it was found to be of use ? " prevented its adoption.

It was the same with the sun-flower (*Helianthus annuum*). Although admitting it would be of great service and profitable to rear, yet " what would be the new exaction " interfered with me in this attempt to benefit the people. Yet these two plants would prove of the utmost value in every respect, particularly the former, which would greatly assist in preventing the cattle from dying of starvation in winter, as they now do.

Mule Road.—From the impracticable nature of the hill paths on the left bank of the Sutlej beyond Wangtu, it was utterly impossible for laden mules to reach the scene of the operations. Thus, in order to be able to convey the provisions to some spot that would be tolerably centrically situated for the work-people, and where I could accumulate and keep a supply of them on hand, I was obliged to make a mule road to Kilba, and without it I can safely say that I never should have been able to accomplish this undertaking, as I could not have fed my imported laborers.

A rough alignment, avoiding the worst precipices as much as possible, was soon made, and August 1867 saw us turn the first sod, although a

fair start did not take place till the November following, it was passable for laden mules into Ramni (6¼ miles from Wangtu), in September 1868, and unto Kilba, by a temporary expedient over the Janee precipice (7¼ miles from Ramni junction) in April 1869, and finished throughout in July of the latter year, having occupied 23 months in its actual construction. Considering the natural difficulties of making a road through a mountainous country, it may be said that it was expeditiously built. The width was six feet. Three mural precipices of granite rock had to be blasted through, and innumerable small rocks had to be circumvented, walling and filling in more or less had to be done, together with three bridges spanning that number of torrents. The cost, including labor, blasting powder and materials, but without any allowance for supervision, &c, was Rs. 32,500.

Provision Stores.—Two were built both being needed to enable us to keep the provisions required to feed the imported laborers.

One was situated at Kilba, the head-quarters of the work, and therefore the largest, as it had to supply the laborers working in the Sapni, Koomkoomee, Kunai, Joompan and Phunla Forests, the other at Ramni, for the use of the men employed in that forest and the adjoining one of Janee. In addition to the foregoing, a powder house was built at Kilba. This was an old cave built up on three sides with rough stones, the forth being a portion of the rock forming the cave.

Bungalows.—Three were built one being over the Kilba store (whereby the same roof answered for the two); the second at Ramni, erected at one end of the store there. These were for our use in the hills; to which I may add that at the permanent camping grounds of Lingnay, and at the mouth of the Phunla Khud, a few huts for servants were constructed. The third one was at Pulhan, in the plains, the head-quarters of the catching and rafting operations.

Cash.—I made a very satisfactory arrangement with a native banker, by which he agreed to remit me all monies required for disbursements in the forests, at a commission rate of 1¼ per cent., taking upon himself all risks and responsibilities from accidents or robberies that might happen in transit from the Bank to our Safe, thus avoiding any chance of loss on our part. Considering that it had to come 134 miles on men's backs,

and that it had to pass eight nights on the road, I think it will be admitted that this was the best method to be adopted.

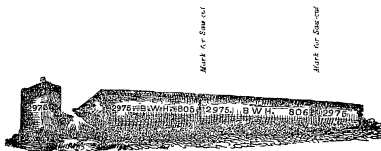
Method of extricating logs from the forests.—Before describing our own operations, I will briefly allude to the primitive mode. Premising that the greater portion of the Pine Forest tracts are situated in the territories of the quasi-independent rajahs bordering our frontier, the process of obtaining a permit (*Chápp*) was very simple, and merely consisted in giving a couple of handfuls of rupees to the rulers, and allowing a certain amount of "palm oil" to trickle down amongst the officials of the Court, (a bottle of brandy has been a good persuader before now), when permission was at once accorded to commence operations.

The operator would then proceed with a gang of men to the scene of his future labors, and fell whatever trees he chose, how and where he liked (there being no supervision, he could do as he pleased) from May to October in any one season, that being the period for which the honorarium he had given was supposed to count. His sole anxiety was to launch everything he had felled, as more than likely somebody else might obtain a permit the following year to fell and launch in the same forest, in which case the new comer would be sure to appropriate any of the logs of his predecessor remaining over from the previous season, even though they might have the first comer's marks.

As regards the method adopted for sliding the logs into the river, no effort beyond allowing the logs to form their own track, and smooth it themselves in their downwards passage was attempted, and it was simply a question which was strongest, wood or stone. Yet so long as not more than 90 *per cent.* of breakages occurred, timber traders realized a fair profit, and were satisfied. That this excess of loss is not exaggerated, the remains of the innumerable broken pieces now lying in the old slides (?) of those days bear silent testimony.

Yet not all timber merchants were so short-sighted as not to see and understand the advisability of improving the slides in their worst parts. The late Mr. M. Ter Arratoon made a small trial in this respect, but it was carried out without any attempt at method or regularity, and was therefore not of great benefit.

I have now demonstrated how the extrication of logs can be effected with a minimum breakage, (even with my necessarily rough and incomplete,

because hurried, arrangements,) at a loss certainly not greater than 15 per cent, which I believe will be about the damage sustained by us, less it may be, but not greater.

Above is a sketch of the marks I adopted for the recognition of our logs on arrival in the plains.

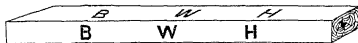
The figures on the left denote the forest number of the tree, and were consecutive from 1 to 8,000, our limit for felling they also corresponded with the figures on the stumps.

The letters in the centre of each log stand for the initials of the Firm —Brassey, Wythes and Henfrey.

The figures on the right denote the number of the log: each forest commencing with No. 1

The above were cut into the sap-wood with an ordinary axe, and cost one anna, or three half-pence, for each log.

The sawn scantlings from Ramni had the initials of the firm branded in on their four sides.

Mark for the Sawn Scantlings

Branded on both sides.

In order to prevent any over or under felling of our limit, and also to avoid any disputes with the native officials of the neighbouring court, I never allowed any work to commence in any forest until the marking had been finished. Just above the root our numbers were cut in deep, as shown in the left hand portion of the sketch, and there they are to this

day, permanent witnesses to our operations in this respect. As soon as a tree was down it was at once cleared of its branches, and then divided off into logs, the spaces had the figures and letters comprising our mark drawn on them by means of charcoal or chalk, and the men set to work to cut them in. Every log was at the same time entered in a book, of which the following is a specimen :—

Koomkoomee Forest.

Distinguished Mark.			Dimensions				Cubic Contents		Name of Mate who cut.
No. of Tree	Marks	No. of Logs	Length.		Girth.				
			Ft	Ins	Ft	Ins	Ft.	Ins	
2,975	B W H	805	12	..	8	2	50	...	Magnee Ram.
		6	12	.	7	6	42	2	"
		7	12	...	6	8	33	4	"
		8	12	...	5	8	24	1	"
2,976	Do	9	13	...	7	4	43	8	"
		10	12	...	6	6	31	3	"
		1	13	...	6	...	29	3	"
		2	13	.	4	8	17	8	"

Thus there was no fear of felling any trees but our own, and we could not well be cheated in paying for more felling, clearing, marking, or logging in any one forest, than what our books showed. Four natives were well broken into this work, and their returns taken daily, and as we were constantly about the forests, we tested the numbers frequently and always found them correct, also the measurements of the dimensions.

The number of the trees made over to us were as follows.—

Janee,	..	..	..	..	1 to 548 =	548
Phinla,	..	..	..	..	549 to 1,858 =	1,310
Do.	..	..	..	..	3,102 to 3,668 =	567
Kunai,	..	.	..	..	1,859 to 2,504 =	646
Koomkoomee,	..	..	..	..	2,505 to 2,902 =	398
Sapni,	..	..	..	..	2,903 to 3,101 =	199
Joompan,	..	..	..	..	3,669 to 6,426 =	2,758
Ramni,	..	..	..	..	6,427 to 8,000 =	1,574
					Total,	8,000

So that by a reference to any left hand number on our logs on arrival in the plains, I could at one distinguish which forest it had come from.

Working Operations Sapni Forest.—This forest (situated on the east side of the spur which runs towards the junction of the Buspa and Sutlej rivers,) although a few years back almost impenetrable, is now bare of trees; the cause—a fire that occurred about seven years ago destroying the whole of the lower portion, and leaving but a wreck above. It is now trying to recover itself, and the natural reproduction is very good where allowed proper action, but no benefit will ever accrue to this or any other one of the forests until properly enclosed. Primarily, each of the paths leading from one village to another, or to their outlying hamlets, require fencing on either side, leaving, say, a space 10 feet between for the passage of goats, sheep, &c., after which attention should be turned to demarcating the upper and lower boundaries. A little judicious thinning amongst the younger coniferæ, and clearing away of scrub to prevent their being choked, is advisable. There are also a number of standing dry, and partially burnt trees, and others that have fallen from the action of wind or snow, these should all be removed to the river: at present they are but so much additional food for fire, should such again happen. Besides they (the two former) attract lightning, and are dangerous from that cause. All the refuse wood should also be gathered together and sent down to the river, it would be useful in the plains for firewood, would cover its own expenses, and would be one element less for ignition. The soil is a very deep rich humus, the collection of centuries of fallen leaves, overlaying gneissoid granite rock. The general slope is about an angle of 35° in the lower portion, higher up it becomes less: the aspect is almost due east. But very few Kelmung trees now remain for felling, although they can be supplemented by the Rai and Lim, which are plentiful in the upper portions of the forest.

The trees marked over to us in this forest were so few in number, that I could not go to great expense for building intercepting walls, so I contented myself with constructing a couple of small rough ones at the two worst places in the slides, just sufficient to give the logs a turn into two hollows, which answered very fairly as natural slides. They also acted as counting places, as the logs once past them went direct into the river Buspa. The logs being collected on these walls, and notice being given,

one of us (Europeans) would go and count them, examine the marks, and then give the order to launch them into the water. However, to be quite sure that none were left in the slides, a foot-path zig-zagged down their sides affording peeps of them throughout, and it was not until a second visit had been made to the counting place, and a trip down the footpath undertaken to see that every log was in the water, that any settlement of account could take place, thus ensuring that no rascalities such as burying or hiding any of the logs could occur.

The following statement will show the cost of putting the logs into the river, and their out-turn. The greater portion of them were cut long, *i.e.*, from 23 to 25 feet

	RS	A.	P.
Marking trees, ...	8	12	0
Felling and clearing trees, and marking and sawing logs, .	520	15	9
Making slides and building two intercepting walls aggregating 350 lineal feet, ...	471	15	0
Compensation to villages for crops destroyed, ..	33	8	6
Launching logs, ...	1,832	0	0
Total Rs.,	2,867	3	3

This forest contained 199 trees, yielding 458 logs, each averaging 68 64 cubic feet, or a total of 31,137 cubic feet, the cost therefore (for labor only, and without any charges for establishment, &c.,) is Rs. 14-6-6 per tree, Rs 6-4-2 per log, Re 0-1 5½ per cubic foot If to the foregoing we add the proportion due for supervision, &c, at Rs. 34-13-5 per tree, Rs 11-4-0 per log, Re 0-5-0 per cubic foot,* we shall have the actual expenditure at Rs. 49-3-11 per tree, Rs. 17-8-2 per log, Re. 0-6-5½ per cubic foot, for extricating timber from this forest The cost of catching and rafting the logs in the plains may be safely assumed at Re. 0-1-11½ per cubic foot, *inclusive* of all charges for supervision, labor and materials. By adding this sum to the total cost of a cubic foot of timber in each forest, the exact cost of landing timber at Phillour can be readily ascertained in each instance.

About two miles of temporary or natural slides, 350 lineal feet of intercepting walls, and 269 mines (of an average depth of eighteen inches each) blasted, comprised the works for assisting the extrication of logs from this forest.

* *Vide* page 415

The trees were in girth, taken at a man's height from the ground, as follows:—

6 feet in girth,	35
7 „	46
8 „	52
9 „	36
10 „	19
11 „	6
12 „	1
13 „	2
14 „	1
15 „	1
Total Trees,	199

being an average of 8 feet in girth for the trees of this forest. A loss of 46 logs, equal to 9 per cent, occurred between forest and river.

The principal implements made use of in these operations are—

The felling axe, weighing about 4 lbs, used for cutting down the trees, clearing them of their branches, and other purposes too numerous to mention. The cross cut saw for converting the trees into logs.

Wooden levers, about 6 feet 6 inches long, 3 inches in diameter (cut from the nearest tree or sapling) with which to move the logs.

Koomkoomee forest.—Situated on the west side of the spur mentioned under the former forest, and to the east of Kunai village. The soil and rock differ in no respect from the previous description, the aspect though is north, and the upper portion of the forest is on a steeper slope than the lower. The auxiliary pines are tolerably plentiful, and in places they appear to be ousting the cedar. Here again demarcation and fencing are greatly required.

The intercepting arrangements here were more elaborate, and consisted of a wall nearly 1,000 feet in length, (the width being twenty feet,) so laid out as to cut across the lower portions of the natural slides, and by its means the logs were conveyed to a certain point, whence they could reach the river with the least damage. But for this they would have gone, some into a streamlet whence further removal would have been difficult, and occasioned great delay in their after progress to the river, and others over an earthen precipice with plenty of large boulders spread about its base,

upon which the logs in their flight would have struck, and the greater portion been smashed. The counting place was on a small plateau, quite at the bottom, being only 40 feet above the Sutlej. Here the logs were collected for launching, so that in this instance there was no fear of paying for any that did not go into the river: thus from the sure and certain testimony of my European assistants, or of my own eyesight, do I know that every log returned as launched has been seen to take its plunge into the water, no *ipse dixit* of a native has been here, or elsewhere, necessary for such a purpose.

The following statements will show the cost of putting the logs into the river and their out-turn, the greater portion of them were cut slightly over 15 feet in length to be available for bridge purposes.

	RS	A	P.
Marking trees, ...	10	8	0
Felling and clearing trees, and marking and sawing logs, ..	1,178	4	7
Making slides and building intercepting wall, 1,000 lineal feet,	1,265	15	4
Compensation to villagers for crops destroyed, .. .	126	14	0
Launching logs, ...	3,148	4	0
Total Rs, ..	5,729	13	11

This forest contained 398 trees, yielding 1,816 logs, each averaging 34·80 cubic feet, or a total of 63,196 cubic feet, the cost therefore (for labor only, and without any charges for establishment, &c.,) was Rs 14-6-4 per tree, Rs. 3-2-5 per log, Re. 0-1-5½ per cubic foot.

If to the foregoing we add (as before) the proportion due for supervision, seigniorage, &c., Rs 34-13-5 per tree, Rs. 11-4-0 per log, Re. 0-5-0 per cubic foot, we shall have the actual expenditure at Rs. 49-3-9 per tree, Rs. 14-6-5 per log, Re. 0-6-5½ per cubic foot, for extricating timber from this forest. A loss of 27 logs, equal to 1½ per cent, occurred between forest and river.

About 3 miles of natural slides, 1,000 lineal feet of intercepting wall, and 961 mines (of an average depth of eighteen inches each) blasted, comprised the works for assisting the extrication of logs from this forest.

Joompan Forest—A distance of 2½ miles as the crow flies, and five by the path, separated this forest from the former three. It is situated on both sides of the spur that divides the Halabgar stream (popularly known

as the Joompan Khud) from the Sdeeling stream (likewise known as the Phinla Khud). This was a virgin forest in every sense of the word, it having been protected from the presence of ordinary timber traders by the rocky nature of the lower portion, rendering the removal of timber, in their non-professional eyes, so extremely improbable, that none of them had ever even dreamt of making the experiment.

In this forest I had to construct eight long intercepting walls to prevent the logs being broken or getting into inaccessible places; five of them were in the east forest, and aggregated 4,020 feet in length, while the three in the western portion amounted to 670 lineal feet; into these dozens of natural slides opened, and a tolerable constant rush of logs has passed over them. The eastern ones were all led to the only available point that offered itself for continuing their course to the river, by utilizing the bed of the Halabgar stream for a short distance from its mouth, by filling it up with stones, and levelling it as well as I could by blasting out the large rocks, and then rough pitching it; the approach to it being an earthen slide (in continuation of a short wooden one) from which large pieces of rock and stones were always escaping, caused by the passage down of the logs wearing away the earthen support from under them, and requiring constant attention in mining out projecting stones, or smash would go the logs. In fact all the breakages in the forests happen in the lower third part of the route, where the face of the country is so rocky and steep; the upper two-thirds being generally well coated with mould and the slope more favourable, accidents but rarely happen. The bed of the stream was a constant source of worry as it could not be maintained in a permanent state of repair, from the water disarranging, by its force, our attempts at keeping up a fairly even surface, and particularly during the height of the rainy season was this the case. Last year (end of July), owing to a delay in bringing some logs to the counting place, the annual flood came down and carried off 300 logs at one swoop. Some of the mountain torrents are subject to this, and woe betide everything that may be within its influence. I have known *Koonch* trees, four feet in diameter, torn up and carried, roots, branches, and all, into the Sutlej. During two or three spare intervals, of a few days each only that occurred in the passing of the logs down the intercepting walls, I managed to put in two wooden shoots of the above pattern, and the time they saved, though they were only so small, was immense. I only wished

I could have constructed more of them, but the flood of logs was so

Cross Section on AB.

NOTE
Cost for Labor Rs. 3-8-0 per lineal foot.
1½ seers iron required ditto.

steady, and the men so eager not to be delayed, (doing so might have lost future labor,) that but three opportunities offered either for lengthening or building new ones, and of these I need hardly say I availed myself. The cost per cubic foot calculated similarly to those previously given in detail, amounted to Re. 0-6-10¾ per cubic foot. The sketch of the cross-section of the Phinla Khud (*vide* page 406), will give an idea of the sides of the Halabgar stream, as they differed but slightly, and that only close to the Sutlej, the former running gently down to its edge, while the latter was some 30 feet above it; here also was the counting place, thus no cheating could occur.

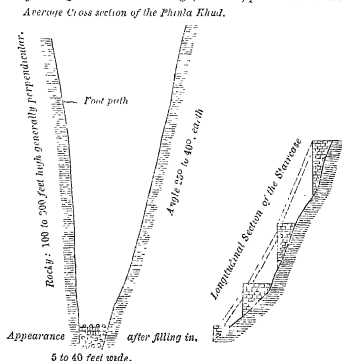
The expenditure for this forest was heavy, but spread over the very large number of logs that had to come out, the proportion is not so very much greater than in the others; and without the accessories of the intercepting walls, I feel confident that not 30 per cent. of whole logs could ever have reached the river, and the greater number of those would have been so much shaken, that on being sawn up, they would have been found unfitted for any purposes requiring strength. The logs were all cut to sleeper length, *i. e.*, about 11 feet. The cost per cubic foot, calculated similarly

to those previously given in detail, amounts to Re. 0-6-10¾ for the out-turn of this forest.

Phinla Forest.—Situated on the east flank of the spur which meets the Sutlej near the mouth of, and separated from the previous forest by, the Sdeeling stream (commonly known as the Phinla Khud.) In connection with these forests of the Himalayas it is a noteworthy circumstance that nearly all the best timber and straightest trees grow on old terraces originally made for cultivation. From particulars that I have gleaned, it appears that, somewhere between 150 and 200 years ago, an epidemic visited the country, and carried off nearly all the inhabitants; in some of the villages only one family out of 15 or 20 escaping! The population being thus so greatly reduced, cultivation could only be carried on over a limited area of the arable lands that had, previous to that event been tilled by the community, the remainder would, therefore, in the regular course of things, return to its natural state, and thus in the course of years the forests gradually but surely spread themselves over the fields and terraces as we now see them. I am inclined to believe that pine forests more or less dense have existed in these hills from time immemorial, and as the seeds retain vitality for a long time when buried in their mother earth, might they not have sprouted when no longer disturbed by the plough? When once a pine forest has taken possession of a place, I feel certain it can never be eradicated (continual fires passing over its site always excepted). The ground becomes so saturated with seed, that although it may be cleared and turned over again and again, yet when left only for a few years, a new forest will commence to be formed. There are many parts of these forests where, if merely hoed just sufficiently to loosen the soil, a most satisfactory result would ensue: a pick-axe used in like manner would also answer. My observations of the various natural slides lead me to this belief, as after a good course of ploughing up from the logs rolling and bumping over them has taken place, if the slide is not touched for sometime tiny coniferæ raise their heads. In one or two instances, logs have again passed over and crushed and scattered these incipient firs, totally changing the surface of the earth, when lo, after another rest, other little fellows have sprouted up, and it is upon this circumstance that I conclude that the soil of a pine forest becomes so impregnated, that natural reproduction follows as a

matter of course, if rest is allowed, accompanied by a thorough system of fencing and enclosure to keep out flocks and herds. The auxiliary firs are here in fair numbers, with the addition of the *span* which is in great abundance near the upper limits of the deodar. The aspect is north east; the soil very good, thin at the top, but increasing in depth about half way down, overlying granite. The slope is very steep in every direction: from 35° to 40° being about the angle of inclination.

Here again intercepting walls were indispensable to prevent the logs from getting into inextricable positions owing to the necessity of bringing the Joompan west forest logs into the same outlet as the Phinla ones; and in order to economize time and labor as much as possible, I was obliged to utilize the Sdeeling stream from about one-third of its distance up. Though the result was disappointing in every way, very expensive, and the source of after delays in the launching operations, yet these causes were quite counterbalanced by the celerity with which I could open out a rough communication between forest and river (was I not working against time, and was not the wood urgently required in the plains?) improving it afterwards as time and opportunities offered. It is quite true that I could have continued the intercepting wall across the spur into a natural slide in the adjoining forest of Punung (A to B, *plate* XXXII.), but the delay in constructing it induced me to overlook its otherwise many advantages, and to give it up. However, as time wore on, we blasted out projecting rocks, and built catching walls at intervals in the Sdeeling stream, so that at last it presented the appearance of a huge staircase. The walls were very strong, being constructed with long

Average Cross section of the Phinla Khud.

wooden ties, length and crosswise, ballasted with large boulders; the narrower portions of the stream had to be filled up to a width of 18 feet. In places wooden ways bolted to strong cross timbers (as in sketch), were laid down to expedite the passage of the logs: rough pitching everywhere had to be done. Each summer season required fresh attentions of like nature, as the body of water being then increased by the melting of the snow, it attained sufficient strength to dislodge some of the smaller boulders. Occasionally the current would change from one side to the other, when, after a certain time, displacement of rocks would ensue, blocking up part or the whole of the roadway, then new projections would crop up requiring smoothing down to prevent interference with the logs. If these matters were not promptly attended to, the contract gangs would desert, and their reports of the difficulties and delays they had incurred would deter others from coming to the works. A reference to the sketch of the slides of this, and the west Joompan forest, will show that the bed of the torrent was the only means of exit, unless I had made two long additional intercepting walls (A to B, C to D, *plate* XXXII.,) one for each forest, and the delay and expense attendent on their construction did not, I considered, warrant my doing so. This forest had likewise never been previously felled in; it too had been protected by the rocky nature of the ground at its lower portion, and thus it was left to me to solve the question, "is extrication possible or not?" The breakage here was greatest of all, partly from having to use the stream, the water rendering the logs so slippery, that when once started, there was no certainty as to their aftermovements: a projecting knob of stone might give

Plan of Wooden Ties and pitching adopted in Phunla Khud.

Longitudinal Section of ditto.

them a turn into a direction they ought not to take, when a flight would ensue, the result being a smash. However the principal damage was caused by a landslip in February 1870, which coming down with great impetus on a large collection of logs (from the previous season's work in the forest) buried them, and injured more or less the thinner ones: nevertheless with the exception of about 100, all have been extricated and launched during the past year. This performance gave me much labor, and caused delay to other parts of the work. A principal hindrance arose also from the fact of the laborers not relishing the idea of working in the water; it was not until daily work became scarce in the other forests that men could be induced to come here.

The cost of moving out timber from this forest was Re. 0-7-5¾ per cubic foot. The loss before reaching the river may be assumed at one-fifth: the two causes of this excessive damage have already been detailed, and therefore it is obvious that extricating logs *viâ* a mountain torrent is a mistake, and should never be attempted again.

The Ramni Forest.—Is situated two miles up the valley of the Melgard, being divided from the Janee forest by the east flank of the spur that runs down to the Sutlej. From its locality no one had ever dreamt of looking at it; and the inhabitants unanimously recorded their conviction that not a cubic inch of timber could ever come out of it. Its position was such, that without a large outlay for roads communicating with the Sutlej, not a stick of timber, whether round or squared, could ever be got out of it, in fact the time had not arrived for utilizing forests of this description placed so far away from the main river.

The Ramni forest is a magnificient one, and contains even now over 2,000 available cedar trees, besides immense tracts of auxiliary firs. Oaks—(Mohru) 9 to 12 feet in girth, and 70 to 80 feet high, abound, and here are deciduous trees in great numbers, amongst the latter may be mentioned Shko, Koonch, Laur, Kakkar, Kashin, Soah, and many others, all really useful trees for various purposes, particularly so for furniture, but which, from their specific gravity being too great for floating, cannot at present be utilized, as there is no means as yet available for transporting them to any market where any reasonable return could be obtained to cover the cost of carriage. The western part of the forest is gradually being burned away, accidental (?) fires are of annual occurrence, doubtless

originated for the purpose of obtaining good grass near home, for flocks and herds. By simply firing the grass above the limits of arborescent vegetation no harm could accrue, as the blaze would not descend, and danger from this source would be removed, while the extra distance for the men to take their sheep and goats is not worth mentioning: a saving of from three weeks to a month in the spring time in obtaining fresh green grass is the real cause of these fires. The old crop is burnt off the face of the ground, and the new soon sprouts up, affording early pasturage to the cattle; but for this arrangement the villagers would have to lay up a supply of fodder sufficient to carry them over that period, and this causing them exertion is objectionable, the more so when the remedy is so handy. While on this subject, I think I must give expression to a theory I have formed as to the reason why the southern slopes of these mountains are so very bare; and that is because they have been more continuously resided upon, from the fact of their aspect being south, and therefore warmer than the opposite slopes, which have a northern aspect. The usual fires have of course annually happened, and these by degrees have slowly but surely exterminated nearly everything but grass. I may add that the epidemic mentioned (at page 404 of this report) does, not appear to have crossed over to that side. The aspect of this forest is both north-east and north-west, the soil deep and good, overlying granite, gneissoid and quartzoze rocks, with the glittering mica and mica slate scattered in places. The slope in the eastern portion is about 30°, while opposite it is nearer 40°. There are several level spots about the little valley, evidently formed from landslips at some former period.

As a last resource, I had to decide upon building roads, sawing up the logs into sleepers and beams, and transporting them out on carts.

When manual labor is employed it is very disadvantageous to gather logs into too large collections, as owing to the inequalities and slope of the ground the men cannot work them off fast enough, and sawing platforms are therefore necessary to this end: about 250 logs was the greatest number we ever got together in any one spot at one time. My own opinion is, that conversion into scantlings previous to removal from the forests is a mistake in every respect, and causes a dreadful waste of material in the forest; and then the hard knocks they receive in the Sutlej on their way down renders the greater portion unfit for any useful purposes. Of this I felt tolerably sure beforehand, as I had had good evi-

dence of a similar fact on the Ravee in 1865, where out of a number approaching 49,000 sleepers, only 30,000 were good for anything, the rest having been too greatly damaged in their transit from the hills to the plains.

In the few spare moments we had, we tried to distil pine oil from the chips that came off the sides of the logs in converting them into scantlings, and the experiment was tolerably successful, and would have been entirely so could but proper time and attention have been devoted to it. With a little more refining, an oil quite equal to Kerosine could be obtained at about half its cost. Up to the point we left off at, the expenditure was about Rs. 1-8-0 per maund (without refining and merely for distilling the oil from the chips.) The idea here was to try and make a sufficient quantity of it to send to Simla for sale, using the mules that brought out the provisions for its transport, and thus by giving the muleteers a return fare lower the prices of the said provisions: this, and not the hope of making any profit on the oil, was the sole reason for making the experiment. So many other matters however engaged our attention, that by degrees the matter fell to the ground from want of opportunity and time to carry it out. The auxiliary firs would yield an annual supply of turpentine oil if properly looked after for such a purpose. A small niche, slightly sloping to one corner, and a tin cup with protruding lip, fixed underneath, would catch all the fluid that those trees could spare; exhaustion should not be resorted to, but merely of its superabundance of the fluid should a tree be made to give: the niches should work up spirally round a tree (like the worm of a corkscrew) at regular intervals, and only one incision in a tree in one year should be made.

In this forest the expenditure amounted to Rs. 62,260-9-3: had the logs been removed in similar manner as in other forests, the cost would have been Rs. 74-5-5 per tree, Rs. 23-11-0 per log, Re. 0-9-3 per cubic foot, for extricating timber from this forest. The natural conclusion to be derived from the forgoing figures is, that until proper communications are first of all constructed between the works and the Sutlej, no attempt to extricate logs or timber from a forest similarly situated should ever again be tried.

But the actual cost of the Sawn Scantlings was much greater as will

be seen from the following table, which shows the details of the out-turn of sawn timber, launched into the River.

Dimensions of scantlings.	No of scantlings launched	Cubical contents in feet.	If solely used for sleepers, would yield.	Remarks.	
12 × 11 × 11	3,074	30,996	6,148	Total pieces of scantlings sawn, ...	12,604
12 × 11 × 5½	2,389	11,945	2,389		
14 × 11 × 11	1,287	15,140	2,574	Total Launched, ...	11,368
14 × 11 × 5½	739	4,346	739		1,236
16 × 11 × 11	607	8,160	1,214	Deduct for 1,110 broken pieces launched, ...	555
16 × 11 × 5½	359	2,413	359		
18 × 11 × 11	338	5,112	676	Leaves for breakage in transit from forest to river, being equal to an average of 5·43 per cent.	681
18 × 11 × 5½	208	1,573	208		
20 × 11 × 11	285	4,789	1,140		
20 × 11 × 5½	197	1,655	394		
22 × 11 × 11	496	9,169	1,984		
22 × 11 × 5½	306	2,828	612		
24 × 11 × 11	351	7,078	1,404	Average contents of each piece of sawn scantlings, 10 cubic feet.	
24 × 11 × 5½	210	2,117	420		
26 × 11 × 11	131	2,861	524		
26 × 11 × 5½	59	644	118		
	11,036	1,10,826	20,903		
Add still to come out, ...	332	3,320	628		
Add for broken pieces, ...	555	4,995	...		
Total ...	11,923	1,19,141	21,531		

Thus each sleeper will have cost Rs. 2-14-2$\frac{1}{3}$, while on each cubic foot of sawn timber has been expended Rs. 0-8-4$\frac{1}{5}$ merely for putting into the water, and without any allowance for supervision, catching, rafting, &c.

Up to the end of 1870 there had reached Phillour 4,474 whole scantlings, and 1,656 broken pieces, out of 8,039 whole, and 791 broken pieces

of scantling launched (August 31st, 1870,) proving that the river must cause serious damage to timber in transit, and in a much greater proportion than occurs in bringing it from forest to river.

Sweeping the River Sutlej.—This was an actual necessity for various reasons, particularly so to try and check the robberies of logs that daily occur. My Assistants, who had the management of this work, had a most unpleasant time of it, as the whole of the villagers inhabiting the valley on either side of the Sutlej were against them, and put every difficulty in their way to try and prevent them carrying out the work in a proper manner. Yet, not only were the villagers against our proceedings in this matter, but likewise the Rajahs through whose territories the river passes.

The favourite method of obliterating marks, and most ingenious every one must admit it to be, is to sodden with water that part of the log where the mark has been cut in, and then to take a good sized stone and pound away. Thus gradually the wood is peeled off, leaving not a trace to show how it was done, or that there had ever been an imprint of any description on any portion of the log. It may be objected that the fact of the logs being cross sawn at the ends would deter the people from touching any of that sort. Not a bit of it. By judiciously chipping one end with an axe, and slightly rounding the other, this drawback is at once removed, and would afford a spectator the idea that it had come from the forests in that state. The operation is so perfect, that detection —unless caught in the act—is impossible. These two kinds of deception will give some slight notion of the difficulties that lay in our path. I might add a third example, which is to run a log up on to one of the numerous sand banks that abound in the lower portion of the river, and there bury it, removing it at such time or opportunity as might prove best suitable.

There is no doubt, but that without this sweeping, the greater part of the logs that have already reached the plains would not have done so, as when the river is on the annual decline, great numbers of them get into side channels, on to sand banks, or perched on solitary rocks mid-stream, and there they remain until such times as the water again rises sufficiently to remove them. In the meantime they are undergoing a frying process from the rays of the sun, which, shining only on the upper portion, while the underside is perhaps in the water or on damp ground, cause longitudinal cracks in them, ruining their value and usefulness. This can be obviated by simply assisting them into the nearest channel, so

expediting their arrival at the depôts. Sweeping gangs, under European supervision, should always be kept up for this purpose.

Here again we had to make foot-paths to enable us to keep as near the banks of the river as possible. Several miles of them were constructed at the worst positions of the route, and where it was difficult or dangerous to proceed along without them.

They were about 18 inches in width. But for them the parts of the river they were intended to serve, and where logs were found to stick in numbers, could not have been visited by us. The logs would have gone on collecting, and we should all have wondered what had become of them.

There are some very bad places in the river, full of large boulders and rocks, the worst ones being under the Rusthall and Dippi Forests, below Serahan, and particularly so at Lakkri Ghât, between Belaspore and Naila, and it is here I feel certain that the principal damage to logs happens. It is a mixture of rapid and waterfall, with the bed below choked with the dèbris of ages, and on this the logs are driven with such force, that breakage ensues, and thus do I account for the innumerable small pieces of timber that yearly reach our depôts. The only remedy, so long as the river is to continue to be the mode of transit for the logs, is to construct a dam about a couple of miles up on the Belaspore side, and make a small canal round, rejoining the river a short distance below. Ten feet wide and about 7 feet in depth would be quite sufficient to float the logs down singly. Another plan would be to catch all logs between Dhair and Seeree, and from the latter place make a line of railway (following the right bank) to Bull for their conveyance past this objectionable rapid.

Catching the logs in the Plains.—The arrangements made for this purpose extended over a lengthened space, (at least 100 miles of river frontage), so as to allow the logs to be caught during daylight, as they are invisible at night, and it would have been too dangerous to send the skinsmen out after dark. To this end there were no less than 31 catching stations fixed at different points on the river between Naila, at the great bend of the Sutlej, and Kurrianah, seven miles above Phillour, so that logs passing the upper stations during the night would be in the neighbourhood of the lower ones towards daylight, when they would be secured. In many places the river is very wide, and is frequently divided into several side channels, which, although capable of floating logs down for three months in the year, during the height of the rains, become,

as the main channel lowers, so many traps to catch our logs. They have been the ultimate cause of great trouble and expense in extricating our logs from their dry beds, an operation which was always performed towards the end of each season, when the depôts and the river were generally cleared, and the results taken down to Phillour loosely, or in rafts, as occasion served. The river is so low in the winter months that logs cannot float far, as they are certain to be brought up by a sand bank. With an average gang of men to keep them together, there is no chance of their going astray, even if taken down in the former manner.

The process of catching the logs is to engage, about the month of May, a certain number of tarroos (men with inflated skins) who watch for the logs, a short distance on the upper side of their respective depôts, and as soon as they observe one coming, jump into the water and swim out to it, roll it over to note its mark, and, if it belongs to their employer, work it gradually to the catching station where it is landed, and at once rolled up the bank out of reach of unexpected floods: the same process is repeated daily throughout the season. As payment is only made on the logs caught and landed, it may be imagined with what eagerness the gangs would rival one another in their efforts to catch the logs, the first one touching it naturally claiming it, and some ludicrous scenes are occasionally enacted by the men in their anxiety to attain their object. The inflated skin sometimes collapses just as the owner is about to touch a log, and under it he most likely goes, amidst the jeers of his more fortunate brethren; however, as the tarroos are all expert swimmers, beyond the loss of a log no harm would ensue. To prevent paying twice over for the logs, each had a store number cut into the sapwood. They were also booked somewhat after the style before-mentioned, as being in use in forests; thus cheating in this respect could not well occur.

The rates for labor under this heading were—

	RS.	A.	P.
Daily laborers, ...	0	2	0
Monthly tarroos (small inflated skins), ...	6	0	0
„ Dreyns, (large „ „), ...	8	0	0
Carpenter, per day, ...	0	4	0
Clearing knots, per 100 logs, ...	3	2	0
Catching logs, per 100, ...	13-4	to	14
(Including landing and rolling up the bank.)			
Catching sleepers, per 100, ...	2	12	0
(Including removing to above high water mark)			

Rafting logs from the Catching Stations to the Depôt at Phillour.—This is the last scene in the life of a "forest" log, as once arrived at its destination, its conversion is so speedy, that further separate existence it has not, and from thenceforward enters into the family of useful necessaries for the comfort of the human race. The rafts generally contain 30 logs, and are taken charge of by 2 or 3 men; the time occupied in proceeding from Pulhan (the head-quarters of the catching and rafting operations, to Phillour being nearly a month in the low seasons of the year, although in June to August, when the river is in full flood, about 8 to 10 days suffice. The rafts are tied together with bamboos (*Bambusa stricta*) laid crosswise, and native twisted rope made of *Moonj* or of *Bhagghar*, and are steered by a couple of long *chooarces* at the tail. At night they moor alongside the bank, proceeding on next morning. It was considered impossible to take logs down during the height of the floods, but the necessity of delivering the timber early and regularly drove us to make the trial, and although some difficulty met us at first from the fears of the tarroos, we overcame that, and now for the last two seasons they have offered no further objections on this score.

We had a couple of boats for inspection purposes, and to examine the side channels in the banks of the river, and although the trips in them, performed during the height of the rains, were attended by danger, particularly so at the different rapids, where, unless the management of the helm was properly looked after, a smash up against the conglomerated sides of the river's bank would ensue, with drowning to follow as a sure result; yet the cold weather excursions were very pleasant. Visits to the different catching stations, or to stray logs about the river, in order to note their positions, and give orders for their due removal, made pleasent breaks in this, otherwise quiet existence.

The rates for labor and materials under this were—

	RS.	A.	P.
Rafting logs (labor only) per 100, ...	29	0	0
Rs. 11, 13, 26, and 30, have been paid at times, dependent on nearness to Phillour or size of logs.			
Rafting sleepers per 10, ...	4	to	5
Moonj rope for tying rafts, per maund of 80 lbs., ..	2	8	0
Bhagghar rope for ditto, per maund of 80 lbs., ...	1-4	to	1-8
Chooarces for guiding rafts, per 100, ...	16	0	0
Bamboos for keeping logs together when in rafts, per 100, ..	1-12	to	2-8
Boatmen, per month, ...	5	0	0

About two annas (slightly under) per cubic foot has been the average cost for catching and rafting our timber up to date, which sum also includes the cost for supervision, purchase of materials, and all charges that have been incurred for this purpose. I should have been very glad to have presented this information in a more detailed manner, separating the labor from supervision, &c., but the particulars of the first two season's expenditure having only been supplied to me by our Chief Office in an abstract form, I am prevented from doing so.

Total Out-turn.—From the details of each forest, it is calculated that 894,389 cubic feet of timber had on May 31st, 1871, been launched from them. The total expenditure for supervision, &c., (to the 31st May, 1871) was as follows :—

	RS.	A.	P.
Purchase money, ...	67,000	0	0
Seigniorage to the Rajah, ...	28,000	0	0
Office expenses (includes Commission for Cash Remittances),	8,476	15	10
Salary Account, ...	86,638	7	4
Travelling Allowances, ...	16,026	9	7
Native Establishment, ...	6,804	4	9
Medical Expenses, ...	436	5	0
Purchase of Tools and Materials, ...	9,093	5	3
„ „ Blasting Powder, ...	3,654	7	3
Carriage of Materials, ...	4,081	14	7
Bungalows, Stores, Huts and Powder Magazine, ...	7,121	2	6
Wangtu and Kilba Mule Road, ...	32,300	14	11
Loss on provisions, &c., ...	22,411	14	4
Law Expenses, ...	2,761	15	9
Bad debts, ...	4,979	2	1
Sweeping the Sutlej, ...	14,702	11	7
Total Rs., ...	3,14,190	2	9

From this has to be deducted the proportions to be recovered from Mr. Arratoon, and waif logs amounting to Rs. 35,448, leaving Rs. 278,742-2-9 to be divided over the out-turn of the forest logs, being an average of 5 annas per foot cube for supervision, as the charges for putting it into the river to be added to the forest labor charges above detailed for each forest. That it is excessive, I admit, but the difficulty of procuring labor in sufficient quantity to carry out the work to a speedy termination is the principal, through not sole cause for it; the other being the necessity of keeping up an extra establishment owing to the diffused positions of the forests, and last, but least, the delay occasioned by the Ramni Forest.

LIST OF TREES AND PLANTS MENTIONED IN THIS ARTICLE.

Kunawuree Name.	Botanical Name.	English Name.
Bhagghar.	Andropogon involutus.	
Breekche.	Quercus Ilex.	Holly leaved Oak.
Chooaree.	Bambusa arundinacea.	Small Bamboo.
Kakkar.	Pistacia Integerrima.	Pistacia.
Kashin.	Rhus Buckiamela.	Sumach.
Kelmung.	Cedrus Deodara.	Himalayan Cedar.
Koonch.	Alnus Nipalensis.	Alder.
Laur.	Acer cultratum.	Maple.
Lim.	Pinus Excelsa.	Lofty Pine.
Mohru.	Quercus dilatata.	Oak.
Moonj.	Saccharum Munja and Eriophorum Comosum.	
Rai.	Abies Smithiana.	Himalayan Spruce.
Shko...	Ulmus campestris.	Elm.
Soah...	Morus Serrata.	Himalayan Mulberry.
Span...	Picea Webbiana.	Himalayan Silver Fir.

J. P. P.

PROFESSIONAL PAPERS

ON

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ERRATA.

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Page 466, line 9, *for* "perimental," *read* "experimental."
,, 470, ,, 18, *for* "no" *read* "on."
,, 485, ,, 4, from foot, *for* "filling," *read* "filing."
,, 499, ,, 10, *for* "Q_3L," *read* "Q_3L_3."
,, 507, ,, 3, *for* "$Q_2N_2 . \frac{Q_1N_2}{Q_2N_2}$," *read* "$Q_2N_4 . \frac{Q_1N_4}{Q_1N_4}$."
,, 509, ,, 29, *for* "planes," *read* "plane."

CONTENTS.

No. XXXIX.

DALHOUSIE CHURCH.

[Vide *Photograph and Plate Nos.* 33, 34 *and* 35.]

Designed and communicated By W. Purdon, Esq., *M. Inst. C.E., F.G.S., and Superintending Engineer.*

The following is the Specification and Abstract of Estimated Cost of a Church about to be executed at the Hill Sanitarium of Dalhousie in the Punjab; drawings of which are given in the accompanying plates.

Specification.

Excavation of Site.—The site chosen for the Church is the "Lohally Gully," on the neck between the Tera and Bukrata hills, and on a small spur of the latter. The stone excavated to be stacked on the site, and the earth to be thrown down the khud along-side the Post Office.

Concrete.—Under all the walls a 2-feet layer of concrete to be given, and under the floor a 1-foot layer, under the lower the concrete to be 3 feet; the concrete to be composed of 1 part stone lime, 1 part sand, 1 part soorkhee, and 4 parts broken stone, and to be put down in 6-inch layers, each layer to be well consolidated before the next.

Ornamental stone work.—To consist of the sand stone found near Mamool, laid in fine lime mortar, and dressed as shown in the accompanying plan. A bond above the plinth, a portion of the buttresses, exterior pillars and mouldings to all windows and panels, string course to upper

windows and upper cornice all round, interior cornice, pillars and arch mouldings, all to be of ornamental stone work. The stone at first to be only approximately cut and finished, afterwards as funds permit.

Foundation masonry.—To consist of the blue slate stone found at Dalhousie, laid in lime, one part sand, and one part soorkhee, only fair sized stones to be used, and no filling in to be allowed with chips.

Plinth masonry.—Same as foundation, only the points to be finer, and care to be taken to have the stone laid in regular courses.

Superstructure masonry.—Same as plinth.

Flooring.—To consist of lozenge shaped slate, and sand stone alternately, or laid in some ornamental pattern in fine lime mortar.

Doors.—To be all sound seasoned Deodar wood, with massive chowkuts and frame-work, the whole to be varnished and furnished with strong ornamental hinges.

Windows.—To have strong seasoned Deodar wood chowkuts, the panes of glass all to be lozenge shaped.

Roof Covering.—16″ × 10″ slates to be used, laid with a $\frac{2}{3}$ lap, and nailed to battens with two nails to each slate, the nails to be either of zinc or galvanized iron, zinc sheeting to be given at ridges and valleys.

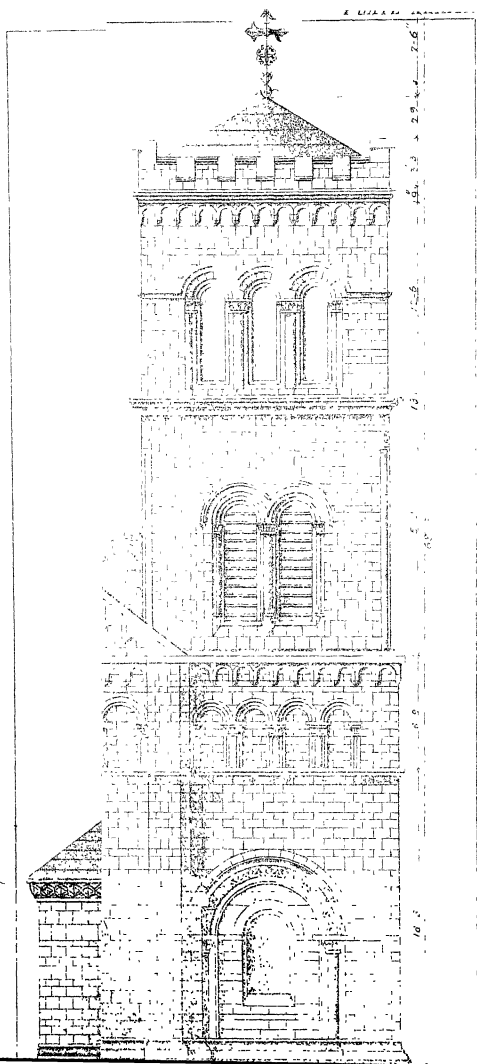
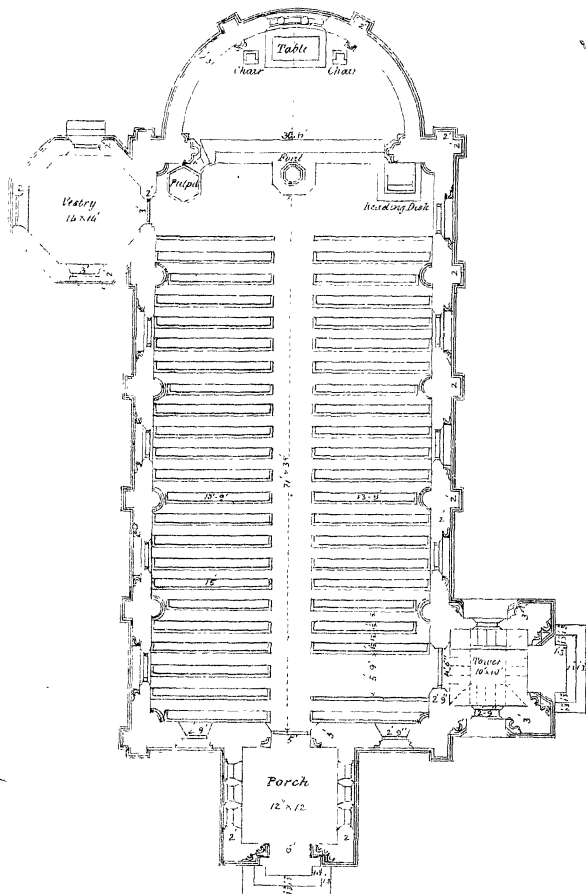
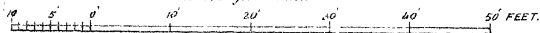
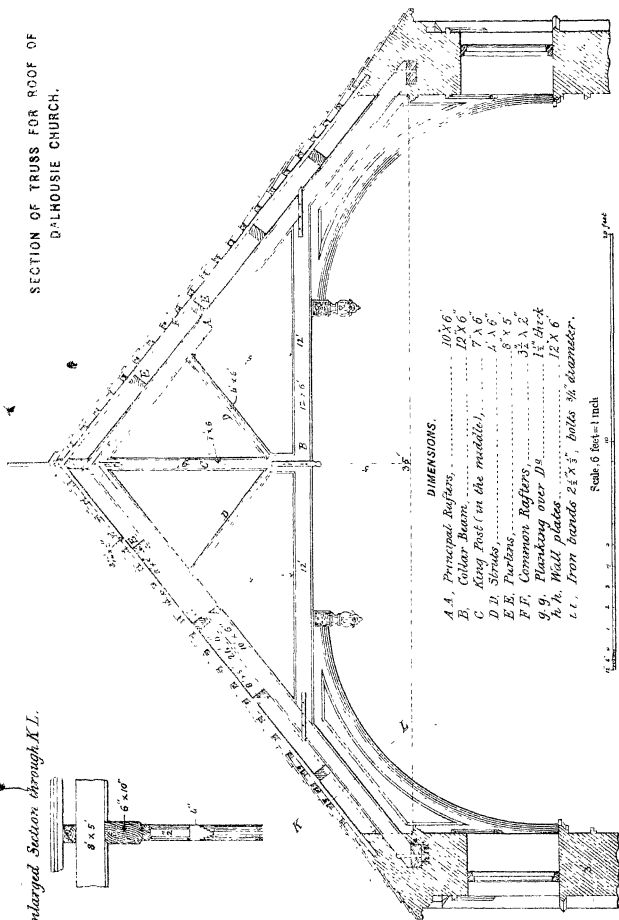
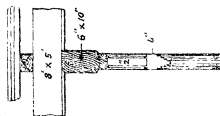
Roof Timber.—To be of sound seasoned Deodar, all exposed surfaces to to be fine dressed and varnished, for detail of measurements, *see Plate* XXXV.

Plastering.—All the interior of the building to be pucka plastered, plaster to consist of one part fine sifted lime, one of soorkhee, with proportions of charcoal, gum and white of eggs with powdered mica.

Pointing.—The whole of the outside faces of the masonry to have the joints and courses drawn, and nicely finished with fine lime mortar.

Seats, Communion Table and Chairs.—To be of the best well seasoned Deodar varnished.

Cast Iron Ridge.—To run along the top of the building $\frac{1}{4}$-inch thick.

Pulpit, Font and Reading Desk.—To be of cut sand stone from Mamool.

DALHOUSIE CHURCH.
GROUND PLAN.
Table
Chair
Chair
Font
Pulpit
Vestry
14×14'
Reading Desk
Tower
10'×10'
Porch
12'×12
Scale, 16 feet = 1 inch
50' FEET.

Enlarged Section through K L.
8" x 5"
6" x 10"
SECTION OF TRUSS FOR ROOF OF
DALHOUSIE CHURCH.
DIMENSIONS.
A A, Principal Rafters, 10" X 6"
B, Collar Beam, 12" X 6"
C King Post (in the middle), 7" X 6"
D D, Struts, 4" X 6"
E E, Purlins, 8" X 5"
F F, Common Rafters, 3½" X 2"
g. g. Planking over Do 1½" thick
h h. Wall plates 12" X 6"
i i, Iron bands 2½" X ⅓", bolts ¾" diameter.
Scale, 6 feet = 1 inch
10
20 feet

ABSTACT OF ESTIMATE.

		RS.
c. ft.		
300,000	Excavation of site, at Rs. 8-8,	2,550
6,315	Concrete under foundations, at Rs. 12,	758
2,574	Foundation masonry, at Rs. 32,	824
1,528	Plinth masonry, at Rs. 34,	520
13,772	Superstructure masonry, at Rs. 36,	4,958
5,616	Ornamental stone work, at Rs. 1,	5,616
s. ft.		
2,158	Flooring, at Rs. 0-8-0,	1,079
114	Doors, at Rs. 2,	228
487	Windows, at Rs, 1-12-0,	852
4,408	Roof covering, at Rs. 30,	1,322
c. ft.		
1,029	Roof Timber, at Rs. 2-8-0,	2,573
mds.		
14¼	Cast Iron Ridge, at Rs. 12,	171
s. ft.		
6,925	Painting, at Rs. 5-8-0,	380
6,318	Plastering, at Rs. 12.	758
32	Seats, at Rs. 30,	960
1	Pulpit, at Rs. 200,	200
1	Reading Desk, at Rs. 50,	50
1	Font, at Rs. 150,	150
1	Communion Table, at Rs. 60,	60
2	Chairs, at Rs. 25,	50
	Total,	24,056
	Contingencies at 5 per cent.,	1,201
	Grand total Estimate,	25,260

No. XL.

INDIAN TIMBER TREES.

By Major A. M. Lang, R.E.,

The following lists contain the names of the most important trees in India, deserving the attention of the Engineer, either as furnishing timber to the carpenter and builder, wood for ornamental turnery, fuel for brick burning, sleepers for railways, or material for other purposes connected with Engineering works. A work of this description is of course no place for *complete* lists of all forest and other trees, and for botanical descriptions: which could not be given within the limits of a few pages, or even of a single volume.

For fuller details on such subjects, works specially devoted to Botany, Forestry, &c., must be consulted: and Balfour's "Timber Trees of India; Cleghorn's "Forests and Gardens of South India;" Skinner's "Indian and Burmah Timbers," may be advantageously referred to by those interested in Indian Trees.

But a brief list of the most important Indian trees, with co-efficients of weight, elasticity, &c., will be useful to every Engineer in the country, and may appropriately be embodied for reference in this work.

It will be observed that the first list contains the *Botanical* names, which only are of real value, and precise application. *Local* names are in general very vague, and not to be depended upon: nor are they of any

Note.—These lists and remarks having just been written for incorporation in the Section on Timber in the new (3rd) Edition of the 1st Volume of the Roorkee Treatise on Civil Engineering, and being still in type, the opportunity has been taken of publishing them also in the Professional Papers, as including a table of useful data for calculations on strength of different timbers in Engineering structures. [Ed.]

use beyond the limits of restricted areas. The same tree will be known by many different names over a tract of a few hundred square miles, and it would tax the best memory to retain all the Indian local names of only one or two trees, and correctly apply them to their own proper localities. Again, one local name may in one district refer to one tree, and in another district to a perfectly distinct plant. Thus the well-known name "Deodar" is applied in Cashmere, Huzara, Gurhwal and Kumaon to the *Cedrus Deodara*: in closely adjacent districts, (Koolloo and Kunawur,) to *Cupressus torulosa*; and in another neighbouring tract (Chumba), to *Juniperus Excelsa*. The Botanical name on the contrary has a precise application to one species of plant alone, and this not only in one country, but among all lands enjoying European civilization. Local names, however, are of course useful, and should be acquired by an Engineer in any district in which he may be employed. A list of a few such names follows the first "Botanical" list: but it must be remembered, that in many cases the identification of local names is very uncertain. *English* names are included in the "local" list; although few (so called) "English" names of Indian trees exist: and in their case also there is great want of precision. For example "Poon" and "Ebony" are terms loosely applied to a large number of trees of many different "species," and even "orders," and as names serving any useful purpose of precise identification are really valueless.

The numbers denoting weight, cohesive strength, &c., have been for the most part taken from the late Conductor Skinner's useful work on "Indian and Burman Timbers." The *precise* meaning of each separate expression in these formulæ should be carefully realized, before using the formula.*

W denotes the weight *in lbs.* of a cubic *foot* of *seasoned* wood.

E_d is the co-efficient of *elasticity* as involved in Barlow's formula,

$$E_d = \frac{L^3}{bd^3}\frac{W}{\delta}$$

where E_d is a constant for each kind of wood, derived from experiment, and

* In using this value of E_d, it should be borne in mind, that the E (= Modulus of Elasticity) of Rankine's and Stoney's tables, (which coincides also with F of Molesworth's elasticity tables) is 432 E_d of this formula, while Barlow uses two separate values of E (Elasticity); in his first tables the $E = 1728\ E_d$, and in the second tables, his $E = 54\ E_d$.

The modulus of rupture (f) of Rankine's tables is $= 18p$. of these tables: while in Molesworth's tables, the co-efficient of transverse strength is $3p$.

With these corrections, the values given in the tables alluded to, can be used in these formulæ and comparisons instituted between the values of the English and other woods entered in those tables, and the values for Indian woods herein given.

recorded in tables: L length in *feet*, b breadth and d depth both in *inches*, of a beam *supported* at the ends, and carrying at *centre* a weight W, in *lbs.* δ being the deflection at the centre in *inches* (*say* for timber $\frac{1}{480}$ of the clear bearing.)

f_t is the constant for each wood denoting the direct cohesion in lbs. per square inch, and applicable to the formula,

$$P = A f_t$$

where P is the weight in *lbs.*, which would tear asunder a piece of timber whose transverse section has an area of A square *inches.*

p is the constant of strength in *lbs.* for timbers subjected to cross strain; and is applicable to the formula,

$$P = \frac{bd^2}{L} p.$$

Where P is the weight in *lbs.* at the *centre*, which would *break* a scantling *supported* at the ends having a clear bearing in *feet* = L, and a breadth = b, and depth = d both in *inches.*

These equations are constantly in use, as explained in the section on "Strength of Materials," in the Roorkee Treatise on Civil Engineering and the numbers given will be found useful for reference. Where more than one number is given for the same co-efficient, it will be understood that these are the results of different sets of experiments, carried out at different times and places, by different persons. In fact the same species of tree will furnish timber of very different quality, in different regions, and even in different parts of the same region: a fact which explains the extraordinary diversity in the statements, and opinions recorded by different competent and reliable observers: one authority describing a tree as lofty and furnishing large scantlings of fine timber: another alluding to it as a small tree supplying no timber of any size or use. So well known and valuable a tree as the *Deodar* will furnish an imperishable timber of immense scantling, if grown on some bleak northern granite slope of the inner Himalaya; while a comparatively soft and inferior wood is produced by the rapidly grown trees of moister forests on the lower slopes nearer the plains. It is advisable, therefore, for the Engineer to ascertain for himself the quality of each description of timber in the actual locality in which he himself is employed: to make experiments to determine its strength, &c., and be careful to utilize each sort properly: not to waste on

some temporary structure a timber which may be a source of great value for some special purpose, while perhaps an inferior wood of no durability is being introduced in some important permanent building. As an example of this, Dr. Cleghorn relates how a small bridge, the total estimate of which was Rs. 250, was constructed of *Poon* spars, which while unsuited for this purpose, would have realized a very large sum for the Dockyards, where this timber is invaluable.

It must be remembered that the Engineer is required not only to know the trees available in his district for providing timber, &c., for the purposes above indicated, but he may also have to plant *avenues* along roads and canals, and should acquaint himself with the trees best suited for such purposes, having regard to the nature of the soil, the amount of humidity, &c. In Northern India the best avenue trees, having green shady foliage almost throughout the year are, Nos. 4, 7, 18, 43, 54, 85, 86, 116 and 117, of the following list; where the usual rain-fall is 25 inches, these trees will thrive with the aid of rain only, after having been raised in nurseries and transplanted at the commencement of the summer rains to their positions at the road side, (where a "thala" should be prepared for each tree). Where, however, the rain-fall averages only 20 inches, it would be difficult to grow avenues of such trees without artificial irrigation, but the "keekar" might be successfully raised from seed sown in trenches where the trees are meant to remain.

In general, avenue trees should be raised in small nurseries, where the ground should be broken up to 15 or 18 inches in depth, and improved with leaf manure; the nursery being furnished with a well, if canal irrigation is not available.

LIST OF THE PRINCIPAL TREES IN INDIA.

N B.—*Trees marked * grow within 50 miles of Roorkee, N. W. P., either indigenous or introduced.*

No.	W	E_d	ft	p

1 ABIES SMITHIANA. (*Coniferæ.*)

A lofty spruce fir of the N. W. Himalaya, dark and sombre, yet graceful with its symmetrical form and pendulous habit. It furnishes a white wood, easily split into planks ; but not esteemed as either strong or durable. It is used as 'shingle' for roof coverings.

2 *ACACIA ARABICA. (*Leguminosæ.*)

| 54 | 4186 / 1111 | 16815 | 884 / 876 |

This well known, yellow flowered, "babool" tree, is widely distributed. It grows rapidly, requiring no water, and thriving on poor soil, dry arid plains, black cotton soil, &c. It seldom attains a height of 40 feet, or 4 feet in girth . its wood is close-grained and tough ; of a pale red color inclining to brown. It can never be had of large size, and is generally crooked. Used for spokes, naves, and felloes of wheels, ploughshares, tent pegs.

3 *ACACIA CATECHU.

| 56 to 60 | | | |

A widely distributed tree, with a heavy, close-grained, and brownish red wood, of great strength and durability : employed for posts and uprights of houses, spear and sword handles, ploughs, pins and treenails of cart-wheels. But the tree is rarely available for timber, being used for the extraction of *catechu.*

4 *ACACIA ELATA.

| 39 | 2926 | 9518 | 695 |

A handsome lofty tree, suitable for avenues, and furnishing logs 20 to 30 feet long, and from 5 to 6 feet in girth. Wood red, hard, strong, and very durable. Used in posts for buildings, and in cabinet work.

5 ACACIA LEUCOPHLÆA

| 55 | 4086 | 16288 | 861 |

This very thorny, white barked "keekur" is found in most parts of India, and its timber in characteristics much resembles that of *A. Arabica*, and is used for the same purposes.

6 *ACACIA MODESTA.

The *Phulahi* is a common, small, and characteristic tree of many parts of the Punjab, (as the Jullundur and Hoshyarpore districts.) It is well worthy of cultivation for timber in dry sandy tracts of country, and furnishes very hard and tough timber, fitted for making mills, &c.

7 *ACACIA SPECIOSA.

| 55 | 3502 / 3532 | | 793 / 532 |

The 'sirris' is a common tree throughout India, and with its rapid growth, its large head of handsome foliage and sweet scented flowers, is a good avenue tree. It grows to 40 or 50 feet in height and 5 to 6 feet in girth : the wood is said by some writers to be hard, strong, and durable, never warping or cracking, and to be used by the natives of South India for naves of wheels, pestles and mortars, and for many other purposes : but in Northern India it is held to be brittle, and fit only for such purposes as box planks ; and for firewood.

8 ACACIA STIPULATA.

| 50 | 4474 | 21416 | 823 |

This unarmed, pink-flowered acacia, one of the largest of the genus, is found from Dehra Dhoon to Travancore, and in Assam and Burmah. It furnishes large, strong, compact, stiff, fibrous, coarse-grained, reddish-brown timber, well suited for wheel naves, furniture, and house building.

9 ADENANTHERA PAVONINA. (*Leguminosæ.*)

| 56 / 55 | 3103 | 17846 | 863 / 1060 |

A large and handsome tree found in most of the forests of India and Burmah ; though the timber does not enter the market in large quantities. The wood is strong, but not stiff : hard and durable, tolerably close and even-grained, and stands a good polish. When fresh cut it is of beautiful red coral color, with a fragrance somewhat resembling "sandal" wood : after exposure it becomes purple, like rose wood. It is used sometimes as sandal wood : and is adapted for cabinet making purposes.

10 AILANTHUS EXCELSA. (*Simarubaceæ*)

This tree grows in Southern India, and is found also in Oudh, and other parts of Northern India, apparently as an introduced tree. It is a remarkably rapidly growing tree and consequently, though useful for avenues, &c., where shade giving

No. | W | Ea | ft | p |

trees are required to grow quickly, it does not furnish timber of any value. The wood is white, light and not durable; and is used for scabbards, &c.

11 ALBIZZIA ELATA. (*Leguminosæ.*)

| 42 to 55 | | | |

Abundant on the banks of rivers in the Burmese plains. It is used by the Burmese for bridges and house posts it has a large proportion of sap wood, but the heart wood is hard and durable: and in Dr. Brandis' opinion, the wood may eventually become a valuable article of trade.

12 ALBIZZIA STIPULATA.

| 66 | | | |

Grows in forests on elevated ground in Burmah; it has beautifully streaked brown heartwood, which is much prized for cart wheels and bells for cattle.

13 ALBIZZIA *sp.*

| 46 | 4123 | 19263 | 855 |

"Kokoh" is the Burmese name for an *Albizzia*, the wood of which is very much valued by the natives for cart wheels, oil presses and canoes. It is a lofty tree, often having 60 feet of trunk before the first branch is thrown of.

14 ARTOCARPUS HIRSUTA. (*Artocarpaceæ.*)

| 40 | 3905 | 15070 | 711 |

This large, handsome, shady tree grows in Burmah and South east India. It yields the 'anjely' wood of commerce, especially esteemed as a timber bearing submersion in water. It is durable, and is much sought after for dock-yards as second only to teak for ship-building it is also used for house building, canoes, &c.

15 *ARTOCARPUS INTEGRIFOLIA.

| 44 | 4030 | 16420 | 788 |

The common 'jack fruit' tree, is of rapid growth, and reaches a very large size. It is found all over India, and is esteemed both for its fruit and timber, and with its abundant dark foliage and numerous pendent fruit is a handsome object. The wood when dry is brittle, and has a coarse and crooked grain. It is however, suitable for some kinds of house carpentry and joinery; tables, musical instruments, cabinet and marquetry work, &c. The wood when first cut is yellow, afterwards changing to various shades of brown.

16 *ARTOCARPUS LACOOCHA.

| 40 | | | |

The 'monkey jack' with its orange colored fruit is found usually as a cultivated plant near houses in India and Burmah. The wood is used in the latter country for canoes: the fruit is eaten, and a yellow dye is obtained from the root.

17 ARTOCARPUS MOLLIS.

| 30 | | | |

An immense tree on the hills of British Burmah, having an average length of trunk to the first branch, of 80 feet, and girth of 12 feet, 6 feet above ground. The timber is used for canoes and cart wheels.

18 *AZADARACHTA INDICA. (*Meliaceæ.*)

| 50 | 3183 / 2672 | 17450 | 720 / 752 |

The beautiful and well-known 'neem" tree, is common throughout India and Burmah, and is much esteemed for ornament and shade. It grows in the stoniest soil. The wood is hard, fibrous, and durable, except from attacks of insects: is of a reddish brown color: and is used by the natives for agricultural and building purposes. It is difficult to work, but is worthy of attention for ornamental woodwork. Long beams are seldom obtainable; but the short thick planks are in much request for doors and door frames of native houses, on account of the fragrant odour of the wood.

19 *BAMBUSA. (*Graminaceæ.*)

| (Plains) | 2801 | | 686 |
| (Hills) | 5735 | | 970 |

There are many distinct species of bamboo, all of which are applied to numerous useful purposes: bridge building, scaffolding, ladders, water pipes, rafts, roofing, chairs, beds, &c. They are of all sizes up to 60 feet in length, and 8 inches diameter. The bamboo is the most generally useful of all the vegetable products of India, and experiments seem to show that it is stronger than any other Indian wood. It is *Endogenous*, being in reality a gigantic grass.

20 BARRINGTONIA ACUTANGULA. (*Myrtaceæ.*)

| 56 | 4006 | 19560 | 863 |

A large tree common to India generally and Burmah: 30 feet high; 4 feet in girth; flowers red. The wood of a beautifully red color, tough and strong, with a fine grain and susceptible of good polish. It is used in making carts, and is in great request by cabinet makers.

21 BARRINGTONIA RACEMOSA.

| 56 | 3845 | 17705 | 819 |

This tree is a native of Southern India, the Moluccas, &c.: and when in blossom is showy with its large rose-colored flowers.

No. | W | Ed | Jt | P |

The wood is lighter colored, and close-grained, but of less strength than that of the last named species It is used for house-building, and cart framing, and has been employed for railway sleepers.

22 *Bassia Latifolia. (*Sapotaceæ.*)
| 66 | 3420 | 20070 | 760 |

The "Mahwah" a well known Indian tree is in most districts preserved for its large fleshy flowers which are eaten and used in distilling arrack. The wood is, however, sometimes used for doors and windows and furniture : but it is said to be eagerly devoured by white ants.

23 Bassia Longifolia.
| 60 | 3174 | 15070 | 730 |

A common tree in Southern and Central India, esteemed for its edible flower and fruit, and the oil extracted from its seeds. For these reasons it is not commonly considered a timber tree, though in Malabar where it attains a large size, it is used for spars, and is considered nearly equal to teak though smaller.

24 *Bauhinia Variegata. (*Leguminosæ.*)

This and other species of the genus are valuable, not for their timber, but as ornamental trees for avenues, &c., having beautiful conspicuous flowers : the centre wood is hard and dark like ebony, but seldom large enough for building purposes.

25 Bauhinia Vahlii.

Some species of Bauhinia are scandent plants : and among the largest of these is the "Elephant Creeper" (a name applied also to *Argyreia nervosa*) which destroys hundreds of valuable timber trees in the Sal Forests of Northern India, where one of the most arduous duties of the forest department is the eradication of these gigantic creepers whose cable like stems form festoons from tree to tree.

26 Berrya Ammonilla. (*Tiliaceæ.*)
| 50 | 3836 | 26704 | 784 |

'Trincomallie' wood is indigenous to Ceylon whence large quantities are annually imported into India ; but the tree has also been introduced into South India. It is the most valuable wood in Ceylon for naval purposes : and furnishes the material of the Madras Masoola Boats : it is considered the best wood for capstan bars, cross trees, and fishes for masts. It is light, strong and flexible, and takes the place of *Ash* in Southern India for shafts, helves, &c.

27 Betula Bhojputra.

This is the best known of the Himalayan birches, and is valuable for its abundant loose bark used as paper, and for lining baskets, hookah tubes, &c. : also as a layer over the planking for roofs to receive the tiles or terrace in the native houses in Tibet, &c.

28 Bignonia Chelonoides. (*Bignoniaceæ*)
| 48 | 2804 | 16657 | 642 |

This tree with its large fragrant, brownish orange colored flowers, is considered sacred by the Hindoos, and is consequently not largely available as timber. The wood is highly colored, orange yellow, hard and durable : a good fancy wood and suitable for house building. It is found in Southern India and Assam.

29 Bignonia Stipulata.
| 64 | 5033 | 28998 | 1386 |

A flowering tree of the Tenasserim forests which furnishes logs 18 feet in length, and 4 feet in girth, with strong, fibrous elastic timber, resembling Teak, used in house building, and for bows and spear handles. This is one of the strongest, densest, and most valuable of the Burman woods.

30 *Bombax Heptaphyllum. (*Bombaceæ.*)
| | 2225 | 6951 | 678 |

The large and stately Red "Cotton" tree is widely distributed throughout India and Burmah. Its light loose-grained wood is valueless as timber, but is extensively used for packing cases, tea chests, and camel trunks : and as it does not rot in water, it is useful for stakes in Canal banks, &c. It is a rapidly growing tree, and long planks three feet in width can be obtained from old trees.

31 Borassus Flabelliformis. (*Palmaceæ.*)
| 65 | 4904 | 11898 | 914 |

The "Palmyra palm" is inferior only to the Date and Cocoanut palms to the natives of Asia. The sap furnishes Toddy, the seeds are eaten, the leaves are used for thatching, mats, baskets, and for writing upon : while the timber, which is very durable and of great strength to sustain cross strain, is used for rafters, joists and

No.	W	E	ft	p	
					battens. The trees have however to attain a considerable age, before they are fit for timber.
32	BRIEDELIA SPINOSA. (*Euphorbiaceæ.*)				A large tree of Central and Southern India, with strong, tough durable, close-grained wood, of a copper color, which, however, is not easily worked. It is employed by the natives for cart building and house beams: and is also used for railway sleepers. It lasts well under water, and is consequently used for well curbs.
	60	4132	14801	892	
33	*BUTEA FRONDOSA. (*Leguminosæ.*)				The '*dhak*' tree, with its brilliant scarlet blossoms, is widely distributed throughout India, and often forms large tracts of low forest. The wood is generally small or gnarled, and used only for firewood. In Guzerat, however, it is extensively used for house purposes; and deemed durable and strong. The flowers give a bright yellow dye.
34	BUXUS NEPALENSIS. (*Euphorbiaceæ.*)				The Himalayan box, which is found in the North West Himalayas, but no where abundantly, furnishes a very valuable wood for wood engraving; but not equal in closeness and grain, or hardness, to "Turkey" or European box. It can, however, be used for all but the finest wood engraving, and is largely employed for this purpose at the Thomason C. E. College, at Roorkee.
35	BYTTNERIA SP. (*Byttneriaceæ.*)				This tree is abundant in Tenasserim, and furnishes a wood of great elasticity and strength, invaluable for gun carriages. It is used by the Burmese for axles, cart poles, and spear handles.
	63	4284	26571	1012	
36	CÆSALPINIA SAPPAN. (*Leguminosæ.*)				This tree is widely distributed through South-Eastern Asia, and is an important article of commerce; but from its value as a dye-wood, it is not available as timber: though it is admirably adapted for ornamental work, being of a beautiful 'flame' color, with a smooth glassy surface, easily worked, and neither warping nor cracking.
	60	4790	22578	1540	
37	CALAMUS. (*Palmaceæ.*)				There are many species of this genus, furnishing the rattan canes of commerce which are used for "caning" chairs, light carriages, &c. To the Engineer they furnish materials for suspension bridges of considerable span: the natives of the Khasia hills make single spans of 300 feet with these strong and flexible canes.
38	CALOPHYLLUM AUGUSTIFOLIUM. (*Guttiferæ.*)				This is one of the trees furnishing the valuable 'Poon' spars: used in ship building. The trees are becoming scarce on the Malabar Ghâts, and should be conserved. Drs. Roxburgh, Gibson, and Cleghorn concur in stating that *C. Augustifolium* furnishes the *Poon* spars of commerce: but *C. Inophyllum* also, as well as *Calysaccion augustifolia*, *Dillenia pentagyna*, and *Sterculia fætida* also furnish timber often termed *Poon*.
	45	2914	15864	612	
39	CALOPHYLLUM LONGIFOLIUM.				A tree of Pegu and Maulmein, furnishing a red wood, excellent for masts, helves, &c., and also (when well cleaned and polished) for furniture: but it does not appear to be abundant. The timber of this tree is sometimes termed "Red Poon."
	45	3491	16388	546	
40	*CAREYA ARBOREA. (*Barringtoniaceæ.*)				This tree grows in most parts of India of a good size, and furnishes a tenacious and durable wood, which admits of a fine polish. It does not, however, appear to be much used as timber except in Pegu, where it grows to a very large size, and is the chief material of which the carts of the country are made, and the red wood is esteemed equivalent to Mahogany. It is useful as a shady avenue tree.
	50	3255	14803	870	
	56			675	
41	*CASUARINA MURICATA. (*Casuarinaceæ.*)				This fir-like tree, imported from Tenasserim, is common now in most parts of India, in avenues, gardens, &c. It thrives best in sandy tracts, especially near the sea. It yields a strong, fibrous and stiff timber of a reddish brown color. It grows with great rapidity: and is admirably fitted for stakes in Canals, &c.
	55	4474	20887	920	
42	*CATHARTOCARPUS FISTULA. (*Leguminosæ.*)				This is an ornamental tree for avenues, and gardens, scarcely to be surpassed in beauty when covered with scented masses of yellow pendulous blossom. It is found all over Southern Asia, but generally as a small tree, whose close-grained, mottled, dark brown
	41	3153	17705	846	

No. | W | Ed | ft | p |

wood is suited for furniture : in Malabar, however, it grows large enough to be used for spars of native boats.

43 *CEDRELA TOONA. (*Cedrelaceæ.*)

| 31 | 2681 3568 | 9000 | 560 |

The "Toon" is a valuable tree found throughout India, and yields a wood extensively used by furniture and cabinet makers; which though not strong, is light, aromatic, close grained, beautifully veined, easily worked, and susceptible of a high polish.

44 CEDRUS DEODARA. (*Coniferæ.*)

| | 3565 3205 3925 | | 456 586 517 655 |

This handsome tree of the North West Himalaya furnishes a fragrant, almost imperishable, timber of great value in roof and bridge building, and for railway sleepers. It is considered to be identical with the cedar of Lebanon. It is the most valuable timber of the Himalayas, where it grows in large forests. The appearance of the tree and value of the timber vary much with the soil, and aspect of the place where it is grown.

45 CHICKRASSIA TABULARIS (*Cedrelaceæ*)

| 42 | 2876 | 9943 | 614 |

This is one of the trees named in commerce "*Chittagong*" wood though occurring also in Burmah, Southern India and Eastern Bengal The wood resembles "Toon" in appearance and aroma, but is more strong and tough, though very liable to warp; it is used as 'Mahogany' by cabinet makers.

46 CHLOROXLON SWIETENIA. (*Cedrelaceæ.*)

| 60 | 4163 | 11369 | 870 |

This tree of Southern India and Ceylon, produces a beautiful yellow wood somewhat resembling 'box' and known as *Satin wood* : it is well adapted for ornamental decoration, and for picture frames is nearly equal to American maple. Logs up to 18 feet long and 6 feet in girth are obtainable in Madras. It is a hard and durable wood, used for posts and rafters, agricultural implements, and wheel naves.

47 COCOS NUCIFERA. (*Palmaceæ.*)

| 70 | 3605 | 9150 | 608 |

The "Cocoanut palm" widely distributed through Southern India and the Eastern Archipelago, is one of the most valuable of trees, chiefly esteemed for its nut, but furnishing also a very hard and durable wood, fitted for ridge poles, rafters, battens, posts, pipes, boats, &c. It grows from 40 to 100 feet high, and 2 to 4 feet mean girth, and thrives best near the sea.

48 CONNARUS SPECIOSA. (*Connaraceæ.*)

A large tree plentiful in the Burmese forests, with heavy, strong white timber, adapted to every purpose of house building.

49 CONOCARPUS ACUMINATUS. (*Combretaceæ*)

| 59 | 4352 | 20623 | 880 |

A large timber tree of Southern India and Burmah, where it reaches a height of 80 feet before the first branch, and a girth of 12 feet at 6 feet above ground The heart wood is reddish brown, hard and durable; used for house and cart building. If exposed to water it soon decays.

50 *CONOCARPUS LATIFOLIUS.

| 65 | 5033 | 21155 | 1220 |

This is an equally large tree as the preceding: but it is more widely distributed, occurring in Northern India, and in the Dehra Dhoon. It furnishes a hard durable chocolate colored wood, very strong in sustaining cross strain. In Nagpore 20,000 axle trees are annually made from this wood. It is well suited for carriage shafts.

51 CUPRESSUS TORULOSA. (*Coniferæ.*)

| | | | |

This is a handsome lofty tree of the North West Himalaya; but is not at all abundant: and being esteemed as sacred (and termed 'dewadara' (deodar) or "god timber" in some hill states) it is not felled or made generally available as timber, though very well suited for this purpose.

52 DALBERGIA LATIFOLIA. (*Leguminosæ.*)

| 50 | 4053 | 20283 | 912 |

This tree is distributed throughout India, but reaches perfection on the Malabar coast. It is perhaps the most valuable tree of the Madras presidency, furnishing the well known Malabar blackwood. The trunk sometimes measures 15 feet in girth, and planks 4 feet broad are often procurable, after the outside white wood has been removed. It is used for all sorts of furniture, and is especially valued in gun carriage manufacture.

53 *DALBERGIA OOJEINENSIS.

A tree 30 feet high, growing in the valleys of the Himalaya, in Oudh, on the Godavery, and in Bombay. The centre timber is dark, of great strength and toughness, especially adapted for cart wheels, and ploughs.

No.	W	Ed	Jt	P	
54 *DALBERGIA SISSOO	50	4022 3516	21257 12072	807 706	There is scarcely a tree in India which deserves more attention than the *Sissoo*, taking into account its beauty and uses, and its rapid growth in every soil. It is said to attain perfection in 28 years. It is widely spread through Northern and Central India, and is more used than any tree for avenues along roads and Canals, and for planting in Cantonments. It furnishes the Bengal Gun-carriage agencies with their best timber, and is the best of all Indian woods for joiner's work, tables, chairs and furniture.
55 DILLENIA PENTAGYNA. (*Dilleniaceæ*)	70	3650	17053	907	A stately and valuable forest tree of Southern India and Burmah, furnishing some of the *poon* spars of commerce. The wood is used in house and ship building. being close-grained, tough, durable, (even under-ground,) of a reddish brown color, not easily worked, and subject to warp and crack
56 *DILLENIA SPECIOSA.	45	3355	12691	721	The *Chulta* is a large and ornamental tree of India and Burmah, with large fragrant white flowers, edible fruit, and light, strong, light brown wood of the same general characteristics with the preceding tree It is used in house building and for gun stocks.
57 DIOSPYROS EBENUM. (*Ebenaceæ*)					The true *Ebony* tree grows in Ceylon and Southern India. This heart wood is deep black, the outer wood is white; with advancing age the black wood increases. It is much affected by the weather, so that it is seldom used, except in veneer, and delicate and costly cabinet work.
58 DIOSPYROS HIRSUTA	60	4296	19830	757	A middle sized tree of Ceylon and Coromandel, furnishing one of the *Calamander* woods of commerce, of a chocolate color, with black streaks and marks, esteemed for ornamental purposes: scarce and valuable. Obtainable in logs 12 feet long, 4 feet in girth.
59 DIOSPYROS MELONOXYLON.	81	5058	15873	1180	This is a very large tree of South India and Pegu, furnishing a valuable wood for inlaying and ornamental turnery, the sap wood white, the heart wood even-grained, heavy, close and black, standing a high polish.
60 DIOSPYROS TOMENTOSA.					This is the North Indian representative of the ebony-producing Southern forms of Dyospyros: occurring in Northern Bengal, Oudh, &c.; a tall elegant tree, furnishing a hard and heavy black wood. The young trees are extensively felled by the natives as cart axles, for which they are well suited from their toughness and strength.
61 DIPTEROCARPUS ALATUS. (*Dipterocarpaceæ.*)	45	3247	18781	750	A magnificent forest tree of Pegu and the Straits, rising 250 feet in height, and 100 feet to the first branch. The timber is excellent for every purpose of house building, but if exposed to moisture is not durable: it is hard and coarse-grained, with a powerful odour, and of light brown color. It furnishes *wood oil.*
62 DIPTEROCARPUS TURBINATUS	45 49	3355	15070	762 807	This is another lofty wood oil tree of Assam and Burmah, and the Andamans, with a coarse-grained timber of a light brown color, not easily worked, and not durable It is used by the natives for house building, in sawn planks, which will not stand exposure and moisture.
63 *EMBLICA OFFICINALIS. (*Euphorbiaceæ*)	46	2270	16961	562	The tree producing the *Myrobalan* fruit, is distributed throughout India, furnishing a hard and durable wood, used for gun stocks, furniture, boxes and veneering and turning. it is suitable for well curbs, as it does not decay under water.
64 *ERYTHRINA INDICA. (*Leguminosæ.*)					A common tree throughout India and Burmah, with a profusion of brilliant scarlet blossoms, whence it is called the "Coral" tree: it furnishes a soft, white, easily worked wood, being light, but of no strength, and eagerly attacked by white ants. It is used for scabbards, toys, light boxes and trays, &c. It grows very quickly from cuttings.
65 *EUCALYPTUS. (*Myrtaceæ.*)					This is not an Indian genus, but many species are now being naturalized in both the Hills and plains of India, imported from Australia. Sufficient time has not yet elapsed to establish the value of the "*Blue gum*" and other Eucalypti when grown in India.

No. | W | E_d | f_t | p |

66 *FERONIA ELEPHANTUM.
(*Aurantiaceæ.*)
| 50 | 3248 | 13909 | 645 |

The tall *Wood apple* tree is widely diffused throughout India, both wild and in gardens and groves: the pulp of the large, hard-shelled fruit is eaten: and the bark furnishes a large quantity of clear white gum known as "East India Gum Arabic." It has a yellow colored, hard, and compact wood used by the natives in house and cart building; and in some places employed as Railway Sleepers.

67 *FICUS ELASTICA.
(*Moraceæ.*)

The Caoutchouc fig tree grows on the Hills of Assam and Silhet, but is to be found as an imported tree in other parts of India. The milky juice is extracted by incisions across the bark down to the wood: 50 ozs. of the juice furnish 15 ozs. of Caoutchouc.

68 *FICUS GLOMERATA.
| 40 | 2113 / 2096 | 12691 | 588 |

The *Gooler* is a wide spreading shady tree, producing great numbers of small red figs growing in clusters on the branches. The wood is light, tough, coarse-grained, and brittle. It is used for door panels, and being very durable under water, for well-curbs.

69 *FICUS INDICA.
| 36 | 2876 | 9157 | 600 |

The well known "Banyan" or "Bur" is one of the commonest trees of India. Its wood is brown colored, light, brittle and coarse-grained, neither strong, or durable (except under water, for which cause it is used for well curbs.) The wood however of its pendent aerial roots is strong and tough, and used for yokes, tent poles, &c.

70 *FICUS RELIGIOSA.
| 34 | 2454 / 2371 | 7535 | 584 / 458 |

The *Peepul* is as widely spread and well known as the banyan, and with it is planted near temples and tombs, and in sacred groves. The wood is similar in appearance, characteristics and uses to that of the Banyan.

71 *GMELINA ARBOREA.
(*Verbenaceæ.*)
| 35 | 2132 | | |

A large forest tree of Central and Southern India and Burmah: a suitable tree for avenues from its size, straightness, and handsome flowers. It has a pale yellow wood, light, easily worked, not shrinking or warping, strong and durable, especially under water: it is however readily attacked by white ants: used for furniture, carriage panels, palkees, &c. In Burmah used for posts and house building generally.

72 (*a*) *GREWIA ELASTICA.
(*b*) GREWIA TILIÆFOLIA.
(*Tiliaceæ.*)
| 34 | 2876 | 17450 | 565 |

In some parts of India these trees are said to reach a large size, but the wood generally is procured in small scantlings, suitable for spear shafts, carriage and dooly poles, bows, and tool handles, for which it is admirably adapted being light, soft, flexible and fibrous, resembling lance wood or hickory.

73 GUATTERIA LONGIFOLIA.
(*Anonaceæ.*)
| 37 | 2860 | 14720 | 547 |

This handsome erect tree with beautiful foliage and dark shade, is much grown as an ornamental avenue tree in Southern India. The wood is very light and flexible, but is not used except for drum cylinders.

74 HARDWICKIA BINATA.
(*Leguminosæ.*)
| 85 | 4579 | 12016 | 942 |

An elegant, tall and erect tree of Central and Southern India, furnishing a red or dark colored, very hard, very strong and heavy wood, useful for posts, pillars, and piles: and excellent also for ornamental turnery.

75 HERITIERA MINOR.
(*Sterculiaceæ.*)
| 61 | 3775 / 4677 | 29112 | 816 / 1312 / 925 |

This peculiar, gloomy looking, tree, known in Bengal as the "Soondree," grows on tracts occasionally inundated by the tides in Tenasserim and the Gangetic Delta, (giving their name to the Soonderbunds) It is the toughest wood that has been tested in India, and stands without a rival in strength, and is used for piles, naves, felloes, spokes, and carriage shafts and poles. It is however a perishable wood, and shrinks much in seasoning.

76 HOPEA ODORATA.
(*Dipteraceæ.*)
| 58 / 45 | 3660 | 22209 | 800 / 706 |

One of the finest timber trees of British Burmah, sometimes reaching 80 feet in height to the first branch, and 12 feet in girth: a large boat of 8 feet beam and carrying 4 tons, being sometimes made of a single scooped-out trunk. The wood is close even grained, of a light brown color.

77 *INGA LUCIDA.
(*Leguminosæ.*)

A very fine and rapid growing timber tree from Southern India, Burmah, Assam, Nepaul, &c., growing to a great height, with sweet scented blossoms, and magnificent, shady, foliage:

No.	W	E_d	f_t	p

well suited for avenues. The heart wood is black, and is termed *Iron wood* in Burmah.

78 INGA XYLOCARPA.

| 58 | 4283 | 16657 | 836 |

This valuable timber tree known as the *Iron wood* of Arracan is found throughout Southern India and Burmah, furnishing a wood of very superior quality, heavy, hard, close-grained, and durable, and of a very dark red color. It is, however, not easily worked up and resists nails. It is extensively used for bridge building, posts, piles, &c, and is a good wood for sleepers, lasting (when judiciously selected, and thoroughly seasoned) for six years

79 JUGLANS REGIA. (*Juglandaceæ.*)

The *Walnut* is abundant in the villages of the N. W. Himalaya, and its beautiful wood is used for all sorts of furniture and cabinet work in the bazaars of the Hill Stations.

80 *LAGERSTRAEMIA REGINŒ. (*Lythraceæ.*)

| 40 | 3665 | 15388 | 637 |
| 41 | | | 612 |

This is a most beautiful flowering tree from South India, Burmah and Assam, but introduced into the gardens of North India for the beauty of its luxuriant purple blossoms. In Burmah it grows to a large tree, and the wood is used more extensively than any other, except Teak, for boat, cart, and house building, and in the Madras gun carriage manufactory, for felloes, naves, framings of waggons, &c.

81 *MANGIFERA INDICA. (*Terebinthaceæ.*)

| 42 | 3710 | 9518 | 632 |
| | 3120 | 7702 | 560 |

The *Mango* is generally diffused over all the warmer parts of Asia, and is much esteemed for its fruit. Its wood, however, is of inferior quality, coarse and open grained, of a deep gray color, decaying if exposed to wet, and greedily eaten by white ants. It is, however, largely used, being plentiful and cheap, for common doors and doorposts, boards and furniture, and also for firewood It should never be used for *beams*, as it is liable to snap off short

82 MELANORHŒA USITATISSIMA. (*Anacardiaceæ*)

| 61 | 3016 | | 511 |

The *Varnish* tree of Burmah forms large forests in conjunction with Teak and Sál, and furnishes a dark-red, hard, heavy, close and even-grained and durable (but brittle) timber, useful for helves, sheave blocks, machinery, railway sleepers, &c.

83 *MELIA AZADARACH. (*Meliaceæ*)

| 30 | 2516 | 14277 | 596 |

The "Persian Lilac" of India which grows throughout China, India, Syria, &c, is ornamental when in full foliage, and covered with sweet scented lilac flowers: but it is deciduous, and bare of leaves for many months, showing then only its bunches of yellow 'beads', so that it is not altogether desirable as an avenue tree, though very much planted for this purpose The soft, red colored, loose textured wood (resembling in appearance cedar) is used only for light furniture

84 *MICHELIA CHAMPACA. (*Magnoliaceæ.*)

| 42 | | | |

A fine timber tree with handsome foliage and flowers. In the Dehra Dhoon it reaches 16 feet in girth. In Mysore, trees measuring 50 feet in girth, 3 feet above ground level are found, and slabs 6 feet in breadth can be obtained, as the wood takes a beautiful polish, it makes handsome tables. It is of a rich brown color.

85 *MILLINGTONIA HORTENSIS. (*Bignoniaceæ*).

A very handsome tree for avenues; tall and straight, with graceful foliage and fragrant white flowers. It grows very rapidly, but is not long lived, and is easily injured by storms. The bark is soft and spongy; the wood is white, fine and close-grained, but of little use.

86 *MIMUSOPS ELENGI. (*Sapotaceæ*)

| 61 | 3653 | 11369 | 632 |

This is an ornamental, more than a useful tree, grown in gardens and avenues throughout India and Burmah, for the beauty of its foliage, and its fragrant white flowers. The wood is heavy, close and even-grained, of a pink color, standing a good polish: and is used for cabinet making purposes, and ordinary house building.

87 MIMUSOPS HEXANDRA.

| 70 | 3948 | 19036 | 944 |

This tree grows in South India and Guzerat, and furnishes wood very similar to the last named, used for similar purposes; and for instruments, rulers, and other articles of turnery.

88 MIMUSOPS INDICA.

| 48 | 4296 | 23824 | 845 |

This is a valuable tree of South India and Ceylon; with a coarse-grained, but strong fibrous durable wood of a reddish brown color; used for house building, and for gun stocks.

No.	W	Ea	ft	p

89 *MORINGA PTERYGOSPERMA. (*Moringaceæ*)

A handsome tall tree, with shady foliage, and of rapid growth. The wood is white and soft; and the scrapings from the root form a good substitute for the horse radish.

90 *MORUS INDICA. (*Moraceæ*)

This species of *Mulberry*, as well as *Morus Multicaulis*, and *M. Nigra*, are common in Northern India. in some parts of the Punjab and Oudh being planted in connection with silk worm rearing. It is also grown in avenues, for which, however, it is unsuited, being for many months quite bare of leaves. The wood is yellow, close-grained, very tough, and well suited for turning.

91 NAUCLEA CADUMBA. (*Cinchonaceæ*)

A noble ornamental tree of India and Burmah, with orange colored flowers sometimes in the latter country, reaching 80 feet in height, and 12 feet in girth. It has a hard, deep yellow, loose-grained wood, used for furniture. In the Gwalior bazaars, it is the commonest building timber, and is much used for rafters on account of cheapness and lightness, but it is obtained there only in small scantlings.

92 *NAUCLEA CORDIFOLIA.

W	Ea	ft	p
42	3052 3467	10431	664 506

This is also a very large tree, with a soft close even-grained wood resembling in appearence Box, but light and more easily worked, and very susceptible to alternations of temperature. It is esteemed as an ornamental wood for cabinet purposes.

93 *NAUCLEA PARVIFLORA.

W	Ea	ft	p
42			400

A large fine timber tree: with a wood of fine grain easily worked, used for flooring planks, packing boxes and cabinet purposes; it is much used by the wood carvers of Saharunpore.

94 *PHŒNIX SYLVESTRIS. (*Palmaceæ*)

W	Ea	ft	p
39	3313	8356	512

This wild "*date palm*" is common all over India, and is valued for the '*toddy*' extracted from it. The trunks are used for temporary bridges, revetment piling, and water conduits. The wood is brown and cross-grained, and not very strong.

95 PICEA WEBBIANA. (*Coniferæ*)

W	Ea	ft	p
88			

The *silver fir*, of the N. W. Himalaya, grows at high altitudes, 8000 to 12000 feet, in dark sombre forests: and reaches from 100 to 200 feet in height, with very short straight lateral branches. The wood is white, soft, easily split, and used as shingle for roofing, but is not generally valued as timber.

96 PINUS EXCELSA.

A handsome lofty pine growing at altitudes of 6000 to 11000 in the N. W. Himalaya, and furnishing a resinous wood, much used for flambeaux: it is durable and close-grained; much used for burning charcoal in the hills: and also for building.

97 *PINUS LONGIFOLIA.

W	Ea	ft	p
	4048 4668 3806 3672		609 735 594 582

The long leaved 'Cheer' pine is the first of this genus obtained in ascending the Himalaya, growing from 2000 to 6000 feet altitude; and being common and light, is largely used in house building. It requires however to be protected from the weather, and is suitable for only interior work in houses. It grows well as an imported tree in the plains as low as Meerut.

98 *PONGAMIA GLABRA. (*Leguminosæ*).

W	Ea	ft	p
40	3481	11104	686

This tree grows all over India and Burmah, and is an excellent avenue tree, reaching in good soil a height of 40 feet, with dense dark green shining foliage all the year round, which, however, is apt to be much disfigured by numberless leaf-mining insects, 'blotching' the leaves. The wood is light, tough and fibrous, but not easily worked, yellowish brown in color, not taking a smooth surface. Solid wheels are made from this wood: it is, however, chiefly used as firewood, and its boughs and leaves as manure.

99 *PROSOPIS SPICIGERA. (*Leguminosæ.*)

A fine timber tree, well suited for dry sandy soils, and furnishing a strong hard tough wood, easily worked. It grows in Mysore and Bombay, but thrives especially in Sindh, where it obtains a large size. It is common also in the Jullundur Doab.

100 *PSIDIUM POMIFERUM. (*Myrtaceæ.*)

W	Ea	ft	p
47	2676	13116	618

The *Guava* is a well known fruit tree of South-Eastern Asia. It is a small tree, and furnishes a gray hard, tough, light, very flexible, but not strong wood: which is very close and fine grained, and easily and smoothly worked, so that it is fitted for Wood Engraving, and for handles of scientific and other instruments.

No.	W	E	f	p	

12 PTEROCARPUS DALBERGIOIDES. (*Leguminosæ*) | 56 | 4180 | 19036 | 861 931 | 49 — This large and handsome *Padowk* tree is a native of the Andaman and Burmese forests, and furnishes a red, Mahogany like timber, prized by the natives above all others for cart-wheels, and extensively used by Government in the construction of ordnance carriages.

13 PTEROCARPUS MARSUPIUM. | 56 | 4132 | 19943 | 868 | — This large and very beautiful tree is widely diffused, and yields one of the most abundant and useful timbers of Southern India, and also the valuable *gum kino.* The wood is light brown, strong, and very durable, close-grained, but not easily worked: it is extensively used for cart framing and house building, but should be protected from wet: it is also well fitted for railway sleepers.

3 PTEROCARPUS SANTALINUS | 70 | 4582 | 19036 | 975 | — The *red sandal wood* tree grows in the forests of South India. Its wood is sold by weight as a dye wood, and exported to England It is heavy, extremely hard, with a fine grain, and is suitable for turnery, being of a dark red color, and taking a good polish.

4 *PTEROSPERMUM ACERIFOLIUM. (*Byttneriaceæ*) — A lofty, handsome, shady tree, suited for avenues: from South India, Assam and Burmah. It has a dark brown wood of great value, and as strong as teak: but its durability has not yet been tested.

5 *PUTRANJIYA ROXBURGHII. (*Euphorbiaceæ.*) — A large shady timber tree with straight, erect, trunk; and with wood white, close-grained, very hard, durable, and suited for turning It grows along the foot of the Himalaya, and in Oudh, Assam, Sylhet and South India.

6 QUERCUS.
(*a*) „ INCANA.
(*b*) „ DILATATA.
(*c*) „ SEMICARPIFOLIA.
(*Corylaceæ.*)
| | | | (*a*) 491 (*c*) 670 |

Numerous species of *Oak* are found in the Himalayas, Sylhet and Malay Peninsula. The three marginally noted, form large forests in the N. W. Himalaya. *Incana* occurring from 5000 to 9000 feet, and *Semicarpifolia* ascending to 12000 feet. They are lofty trees, 80 to 100 feet in height, and furnish serviceable timber: in Dr. Cleghorn's opinion some of the best timber we have. The wood is heavy and for 2 years or more after felling, will not float; hence it has not found its way to the plains by the rivers, as is the case with the pine woods. *Q. Semicarpifolia* in color, and grain resembles the English oak.

7 RHUS ACUMINATA. — The 'Kukkur' of the N. W. Himalaya, furnishes a wood much valued by cabinet makers for ornamental furniture. Planks 8 × 2½ feet can be obtained from some trees.

8 SANTALUM ALBUM. (*Santalaceæ*) | 58 | 3481 | 19461 | 874 | — This is the true *Sandal wood*, and is found abundantly in Mysore. It grows throughout Southern India, Assam, Cochin China, &c., and is sold by weight to be burned as a perfume. It is also valued for making work boxes, and small articles of ornament: and for wardrobe boxes, &c., where its agreeable odour is a preventive against insects.

9 *SAPINDUS EMARGINATUS. (*Sapindaceæ.*) | 64 | 3965 | 15195 | 682 | — The *Soapnut* tree is common to India and Burmah: a handsome tree 30 feet high, and 4 feet girth, furnishing a hard wood, which is not durable or easily worked, and is liable to crack if exposed; but is used by natives for posts and door frames: also for fuel. The tree is valued for its nuts or berries used for washing.

0 *SCHLEICHERA TRIJUGA. (*Sapindaceæ.*) — A tree of Southern India, producing a red strong, hard and heavy wood, used for oil presses, sugar crushers and axles. It occurs also in the East of the Punjab. It is a large and common tree in Burmah, where excellent solid cart wheels are formed from it.

1 SHOREA OBTUSA. (*Dipteraceæ.*) | 58 | 3500 | 20254 | 730 | — The *Thee-ya* is a Burmese species of *sál*, producing a heavy and compact wood, closer and darker colored than ordinary sál, used for making carts, and oil and rice mills.

2 *SHOREA ROBUSTA. | 55 | 4209 4963 | 18243 11591 | 880 769 | — The *sál* furnishes the best and most extensively used timber in Northern India, and is unquestionably the most useful known Indian timber for Engineering purposes: it is used for roofs and bridges, ship building and house building, sleepers, &c. The tree

No.	W	Ed	ft	p	

grows in forests in the Terai extending along the foot of the Himalaya, from the Brahmapootra to the Jumna, and in Burmah and Tenasserim. The timber is straight, strong, and durable; but seasons very slowly, and is for many years liable to warp and shrink.

113 SONNERATIA APETALA. (*Myrtaceæ.*)

A large and elegant tree of the Gangetic Delta, Bombay and Rangoon; yields a strong, hard, red wood of coarse grain, used in Calcutta for packing cases for beer and wine, and is also adapted for rough house building purposes.

114 SOYMIDA FEBRIFUGA. (*Cedrelaceæ.*)

| 66 | 3986 | 15070 | 1024 |

A large forest tree of Central and Southern India, furnishing a bright red close grained wood, of great strength and durability, preferred above all wood by the Southern India Hindoos for the wood-work of their houses. Though not standing well exposure to sun and weather, it never rots under-ground or in masonry, and is very well suited for palisades and railway sleepers.

115 STERCULIA FŒTIDA. (*Sterculiaceæ.*)

| 28 | 3,349 | 10736 | 464 |

A large tree of South India, Ceylon and Burmah In the latter country, the trunk is 50 feet to the first branch, and girth 10 feet, at 6 feet from ground: but the timber is not used there. In Ceylon it is used for house building, and in Mysore for a variety of purposes, taking the place of the true *poon*. The wood is light, tough, open grained, easily worked, not splitting, nor warping: in color yellowish white.

116 *SYZYGIUM JAMBOLANUM. (*Myrtaceæ.*)

| 48 | 2746 | 8840 | 600 |

The *Jamoon* is widely diffused through India, and is valued as an avenue tree from its height, handsome foliage and edible plum-like fruit. The brown wood is not very strong or durable, but is used for door and window frames of native houses; though more generally as fuel. It is however suitable for well and canal works, being almost indestructible under water.

117 *TAMARINDUS INDICA. (*Leguminosæ.*)

| 79 | 3145 | 20623 | 864 |
| | 2803 | | 816 |

The *Tamarind* is a very handsome tree for avenues, gardens, &c., of very slow growth, but attaining a great size; and much valued for its fruit. The heart wood is very hard, close grained, dark red, very hard to be worked; used for turnery, also for oil presses and sugar crushers, mallets, and plane handles; it is a very good brick burning fuel.

118 *TECTONA GRANDIS. (*Verbenaceæ*)

45	3978	15467	814
42			747
		14498	683

The *Teak* furnishes the most useful and durable timber known. It grows in Southern India, Burmah, Java, Sumatra, &c. The wood is brown, and when fresh cut is fragrant: very hard yet light, easily worked, and though porous, strong and durable: soon seasoned, and shrinks little; used for every description of house building, bridges, gun carriages, ship building, &c.

119 TERMINALIA ARJUNA. (*Combretaceæ*)

| 54 | 4094 | 16288 | 820 |

A tree widely diffused, often found in company with teak, and growing to a very large size. It furnishes a dark brown, heavy, very strong wood, suitable for masts and spars, beams and rafters.

120 TERMINALIA BELERICA.

A very large forest tree with a straight trunk, and spreading head, and flowers with an offensive smell. It is a very fine looking tree for avenues, but the wood is white and soft and not used in carpentry.

121 *TERMINALIA CHEBULA.

| 32 | 3108 | 7563 | 470 |

A beautiful and lofty tree with horizontal branches, growing in tiers: planted in gardens and avenues. The wood is used in S. India for common house building, but it is light and coarse-grained, possessing little strength, and liable to warp. In Burmah it is used for yokes and canoes. The fruit and galls are used by dyers.

122 TERMINALIA CORIACEA.

| 60 | 4043 | 22351 | 860 |

A large tree, common in the forests of Central and Southern India, of which the heart wood is one of the most durable woods known: reddish brown, heavy, tough and durable, very fibrous and elastic, close and even-grained: used for beams and posts, wheel and cart building generally: and telegraph posts. It is durable under water and is not touched by white ants.

123 TERMINALIA GLABRA.

| 55 | 3905 | 20085 | 840 |

This valuable timber tree, is found in all the Teak forests of India and Burmah, furnishing a very hard, durable, strong close

No	W	Ed	ft	p	

and even grained wood, of a dark brown color, obtainable in large scantling, and available for all purposes of house building, cart framing and furniture.

124 *TERMINALIA TOMENTOSA. A valuable forest tree of Malabar, Nagpore, Rajmahal, Oudh &c. . which supplies a heavy, strong, durable and elastic wood. It is, however, a difficult timber to work up, and splits freely in exposed situations. A good wood for joists, beams, tie-rods, &c., and for railway purposes, and is often sold in the market under the name of *sál*, but it is not equal to that wood.

125 THESPESIA POPULNEA. (*Malvaceæ.*) | 49 | 3294 | 18143 | 716 | The *Portia* tree of Madras is much used for avenues, from its handsome appearance. It grows most rapidly from cuttings, but the trees so raised are hollow-centred ; and only useful for firewood. Seedling trees furnish a pale red, strong, straight, and even-grained wood, easily worked : used for gun-stocks and furniture.

126 *TREWIA NUDIFLORA. (*Euphorbiaceæ.*) This is a large tree, from 40 to 60 feet in height, furnishing a white, soft, but close-grained wood.

127 ULMUS INTEGRIFOLIA. (*Ulmaceæ.*) This large *Elm* is found in various parts of India, from the foot of the Himalaya to Ceylon. It furnishes a strong wood, employed for carts, door frames, &c. There are other species of Elm *Ulmus Campestris*, *Erosa*, &c., growing in the N. W. Himalaya ; lofty handsome trees, often planted as sacred trees by temples.

128 *ZIZYPHUS JUJUBA. (*Rhamnaceæ.*) | 58 | 3584 | 18421 | 672 | The *Jujube* or *Ber* is a small thorny tree found growing all over India and Burmah, and is cultivated on account of its fruit. The red dark brown wood is hard, durable, close and even-grained, and well adapted for cabinet and ornamental work. The leaves are extensively used to feed cattle in the Punjab.

VERNACULAR INDEX TO INDIAN TREES.

List of Local Synonyms of the Trees enumerated in the Preceding List.

be. *Bengalli.* bu. *Burmese.* c. *Canarese* e. *English.* g. *Gurhwal* h *Hindustani.* k. *Kunawuree.* te. *Teloogoo.* ta *Tamil.*

No. XLI.

PROFILE FOR WALLS RETAINING WATER.

BY E. L. ASHER, *Exec. Engineer.*

[FIRST ARTICLE].

A RIGOROUS theory of hydraulic retaining walls, comprehending all practical considerations, and so furnishing results of reasonable simplicity ready to the hand of the Engineer is one which has never yet been laid down. The subject, on its purely theoretical side, is a simple statical problem, but on its material side there supervene conditions which are difficult to define, and when defined and applied, give rise to more or less, and inevitably to much, of complication.

There have been two kinds of approach to such an object. The one has been the introduction, by certain French Engineers, of graphical constructions which, while being tedious, require also from the operator a complete acquaintance with their theory—such acquaintance being hardly to be gained from the descriptions of their English expounders. The other approach is purely analytical, and is typified by the treatment of Rankine. This method involves equations of rotary and frictional stability only, in the direct method of the author's "Applied Mechanics." In his "Civil Engineering," hydraulic walls are a deduction from his theory of retaining walls in general, and of this theory it is to be said that it involves no more than the above conditions, but affects them by a co-efficient derived from the proportions of existing works, which, rightly or wrongly, introduces a certain element of empiricism. Sufficient, too, as these conditions are for ordinary construction, the law of increase of

pressure of material, both retaining and retained, evidently requires, for extraordinary cases, a condition which, in those investigations, is wholly ignored. The condition, that is, of resistance to crushing in the material. Such a condition involves increase of base in a ratio of squares, which is quite incompatible with any straight sided profile, the only kind considered. Above all, the method is difficult and abstruse, and its results are far from being convenient and accessible to the practical man.

The result remains that the practice of Engineers is really the sole guide to design. Such empiricism, while being as safe as could be desired, is objectionable on graver grounds than those of mere precision. Safety pushed beyond a point of proved sufficiency becomes waste, and there may, and do largely, in this country, occur cases where the cost of the dam in a reservoir is the criterion (often to a few thousand rupees) of the work being undertaken. In such cases, what is called by some, "sound practice," may lead to the abandonment of a promising scheme, and the miscarriage may be more fatal to life and property than would be the bursting of a stinted work. However re-assuring, too, may be the appearance of large masses of material, it is never to be forgotten that water most insidiously searches out defects of work, and most powerfully attacks them. Defects of work in building are held in check by a very finite supervision, which breaks down in proportion as the working face increases, showing an *á priori* advantage for restricted profiles, and an *á fortiori* advantage for such profiles in which certain portions only are indicated for the best and soundest workmanship.

It is not proposed, in the present article, to enter into any mathematical demonstrations. The theory on which results are founded will, with some inevitable repetition, be set forth fully in the end, but it is scarcely to be expected that any one should take the trouble to examine it without some preliminary satisfaction as to the nature of its results; besides which it may be useful to have those results in a compact working form.

The article is therefore confined to a statement of the leading steps, and to exhibiting the practical procedure recommended for the design of retaining walls to still water, or exposed to only moderate currents and waves. Overfalls and stream dams must be reserved for the present as they involve, under this theory, considerations which might at first be objected to as complex.

Finally, it should be observed that the theory assumes a rock foundation. Its absence generally indicates construction in earth and puddle, but should masonry be still adopted, a due extension of foundations would have to be decided on, into which subject it is not proposed to enter.

Admitting that the triangle is the sole geometrical figure which, being equilibrated with a fluid pressure, is so equilibrated throughout, for all its parallel sections: that is, that if ABC is in equilibrium against the fluid pressure on AC, Abc is so against that on Ac, and $Ab'c'$ against that on Ac'. It follows that the triangle is to be taken as the *matrix* for all still water walls, and, by entension, it is convenient to take it as the matrix for all hydraulic walls whatsoever.

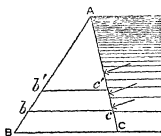



Fig. 1.

Of equal triangles, ABC, A′BC, A″BC, under the same head of pressure, some will have more stability than others, and one will have maximum stability. Or, to take another point of view, triangles of equal stability under the same head will have different bases and areas, and one will have maximum area. This proposition, investigated by the theory of maxima and minima, gives a minimum triangle of rotary stability, or, as it will be briefly called, a minimum profile. And this particular triangle is adopted for a matrix.

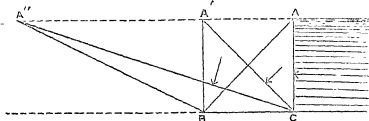
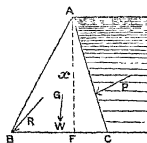



Fig. 2.

It is obtained, for water, by the following simple construction:—

Given

x = the height in feet.

n = specific gravity of the profile—say,

1·79 for brickwork.

2·0 for concrete.

2·3 for masonry.

Fig. 3.

$$\text{Make BC} = \frac{2x}{\sqrt{n^2 + 2n + 9}}$$

set back from the water side

$$\text{CF} = \frac{(3 - n)x}{\sqrt{n^2 + 2n + 9}}$$

Erect FA = X. Join AB, AC. Then ABC is the minimum profile of which AC will be the water face; and any other triangle of equal area will be overturned by the pressure. The profile will be in exact equilibrium, and the resultant of its own weight and of the water pressure will pass through its heel B.

It will be seen that the form of this profile depends entirely on the specific gravity of the material.

The water pressure is now supposed to increase, causing the wall to fail on the joint DE, and over-turning the section ADE.

As the movement commences, the pressures acting on the joint DE will be more and more lightened on the water side of a neutral axis N, and more and more intensified on the land side of it. This neutral axis will, as the action continues, move towards the heel D, until at last the joint will open, when N will have reached, and coincided with it, and vanished. At this instant the whole stress R, compounded of the weight of the wall and the pressure of the water, will be concentrated on the point D. A wedge will be thrown out, and the wall will topple over.

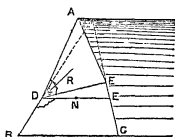



Fig. 4.

It follows then, that if arrangements were made to ensure the stability of the wall, we have here a limit of the stress that can under any circumstances, be brought to crush the material at its back. If then, we should add on material at the back of dimensions calculated to resist this crushing force distributed over it, we should, at the same time, be giving stability by retreating the heel. And if it should appear that the amount of this retreat is sufficient to remove all chance of mere disturbance (and very little should suffice to do that if we assume the water to be still, to which case every other will, by proper allowances, be reduced) it will follow that we have here a sufficient provision against all that can attend the occurrence of a failure which cannot even occur, and, *á fortiori*, a provision for security in the integral structure.

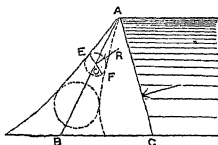
It cannot here be too strongly insisted, to prevent objections to the co-efficients which will hereafter be proposed, that this force R is *not* to be considered as an actual force in practice, concentrated at the back and tending to detrude it. In practice it will really be distributed in some varying ratio along the whole breadth of the joint. We are making provision for a hypothetical and impossible—a limiting and immensely extreme case, under which a quantity of material should be disposed at, and about the point D, sufficient to resist crushing by a certain stress R distributed over it, and which by its own inertia must render it impossible that such condition of strain should ever supervene.

Let ABC be a minimum profile. This surface of resistance would evidently be provided by setting off OE, OF from the back AB, perpendicular to R, so that EF should not be crushed by R distributed over it. The result will be ensured by describing a circle of radius OE round O, and making the rib tangential to it. If we do this for a number of points along the back AB, and draw lines tangentially between all these circles, their envelope on either side will define this rib of resistance.

Fig. 5.

Expressions are therefore investigated for P, W, and their resultant R, from which is deduced a general expression, in terms of the depth x, for the radius ρ of this tangent circle. This furnishes an approximate equation for the rib, from the quadrature of which the weight of the half rib is obtained. Equations are then recast to include this weight, and the result is the following finished value of the radius ρ at any depth x from the vertex, p being the safe crushing strain for the material in lbs. to the square inch, and n its specific gravity.

$$\rho = \frac{9\cdot5906}{p} \sqrt{\frac{5n^2 - 8n + 9}{n^2 + 2n + 9}} \left(\frac{0\cdot016}{x} + \frac{n}{864p}\right) x^3$$

p and n are constants fixed once for all, and which being inserted in this equation, and the co-efficients reduced by calculation, bring it to the simple working form

$$\rho = \alpha \left(\frac{\beta}{x} + \gamma\right) x^3$$

α, β and γ being numerical co-efficients. By giving x successive values for fixed depths, the corresponding values of ρ at once follow.

The co-efficient n should be fixed by experiment on the weight of the material.

For the co-efficient p data are scanty and variable, safe compression for masonry being stated at from less than 30 or 40 to more than 100 lbs. per square inch. Considering the nature of this theory, and the fact that none but the soundest work should ever be introduced into this rib, the accompanying diagrams are calculated on $p = 100$.

At this point an analytical extension of Rankine's theory is made, and a tabulation of results proves that of equally effective walls under that theory, those are more and more economical which have an increasing departure of their water face from the vertical, the most effective being that in which the water face batters to $70\frac{1}{2}°$, giving a base 0·468 of the height for masonry of 144 lbs. to the cubic foot. The straight line at the back of each profile in diagrams 1, 2, 3, shows the full extent to which Rankine's criteria are satisfied, and also the sensible co-incidence of all results up to a depth of some 50 feet. It is further suggested that, to set all questions of frictional stability at rest, it would be well to cant the courses to the water.

Finally, the profile is completed by a correction for the moderate waves and currents which ordinarily occur in reservoirs, the result being an addition to the head which, for the purposes of the present paper, may be taken at 5 feet.

The net result is a wall having a plane battered face to the water, a horizontal top, and at back, a curved or polygonal batter forming the face to a sort of dorsal rib, into which should be thrown all the best workmanship. Further recommendations are that bond courses of such workmanship connect it with a sound and water-tight face, and that in view of possible leakage, frequent weepers be provided through the rib.

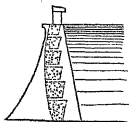
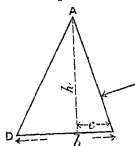



Fig. 6.

The present article will be concluded by recapitulating the steps to be taken in tracing such a profile as has been described, and Diagrams 1, 2 and 3, *Plate* XXXVI., are referred to for illustration.

The working height h is the height of the water surface from foundation, plus 5 feet. On completion of the profile, this 5 feet will be cut down from the vertex, giving true water surface, and a splash wall will be substituted for the frustum.

I.—If the constants be granted as assumed, copy the corresponding diagram to the depth required.

Fig. 7.

II.—If other values be taken for the constants.

Draw a minimum profile, of height h

$$b = \frac{2\,h}{\sqrt{n^2 + 2\,n + 9}} \qquad c = \frac{(3 - n)\,h}{\sqrt{n^2 + 2\,n + 9}}$$

n being specific gravity of the material.

Divide the height h into tens of feet from the top, and rule horizontal lines. At their intersections with the back AD describes circles of radius ρ given by

Fig. 8.

$$\rho = a\left(\frac{\beta}{x} + \gamma\right)x^3$$

in which $a = \dfrac{9 \cdot 5906}{p}\sqrt{\dfrac{5\,n^2 - 8\,n + 9}{n^2 + 2\,n + 9}}$

$$\beta = 0 \cdot 016$$

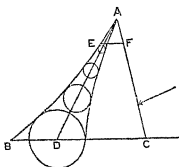
$$\gamma = \frac{n}{864p}$$

$x =$ depth below apex A

$n =$ specific gravity of material.

$p =$ safe compressible strain per square inch.

Draw tangent curves to these circles, defining the rib.

Fig. 9.

Cut off 5 feet from the top and the profile BEFC is complete.

PROFILE FOR WALLS RETAINING WATER

DIAGRAM 1
BRICK.

Theoretical H W Level.
True H W Level

$= 100. \quad n = 1.792$

$(\frac{0.016}{x} + 0.00002)\,0.078587\,x^3$

x	ρ
0	0.000
10	0.128
20	0.518
30	1.179
40	2.123
50	3.160
60	4.879
70	6.746
80	8.897
90	11.383
10	14.217

29.9 — 50.3 — 58.5

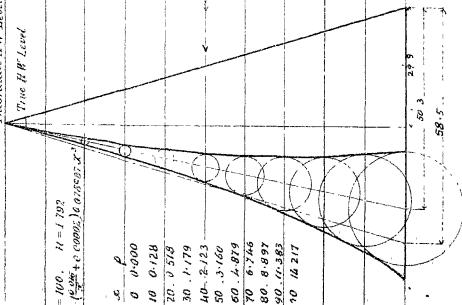



DIAGRAM 2
CONCRETE.

Working H W Level
True H W Level

0, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100

$p = 100 \quad n = 2.$

$\rho = (\frac{0.016}{x} + 0.00002)\,0.083868\,x^3$

x	ρ
0	0.000
10.	0.136
20.	0.55
30	1.259
40	2.210
50.	3.596
60.	5.235
70	7.235
80.	9.576
90	12.271
100	15.348

24.2 — 48.5 — 55.5

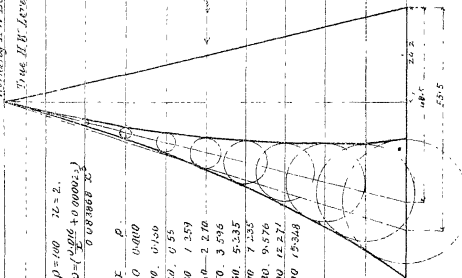
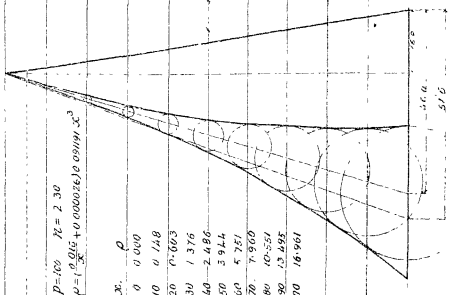



DIAGRAM 3
MASONRY.

$p = 100 \quad n = 2.30$

$\rho = (\frac{0.016}{x} + 0.000026)\,0.091191\,x^3$

x	ρ
0	0.000
10	0.148
20	0.603
30	1.376
40	2.486
50	3.944
60	5.751
70.	7.960
80	10.551
90	13.495
100	16.961

16.0 — 46.4 — 51.6

It will be observed that this dorsal rib is the locus of a generating circle whose radius is a function in the third degree of the depth. It is therefore evident that at some depth, this radius will exceed the base of the minimum profile, which is a function in the first degree of the depth. Beyond this depth, the water face will cease to be a plane, and these expressions will cease strictly to apply.

The depth will exceed any that are ever likely to occur in practice, but it will be well to note it as a corroboration of this theory that where this point *is* reached, the hypotheses which have been here called extreme, are realised, and our limiting strains become actual strains. That is to say, beyond these great depths the profile is only sufficient, and the straight backed profiles *fail*. This, too, is a corollary from the increase of pressure by squares.

No. XLII.

THE PLANIMETER.

By John Elliott, Esq., M.A., *Fellow of St. John's College, Cambridge, and Professor of Mathematics at the Thomason C. E. College.*

The object of the present article is to describe the planimeter, and to prove mathematically the property upon which its construction depends.

The planimeter is an instrument devised to measure by mechanism plane areas bounded by any curve whatever.

Several have been constructed by different inventors, all of which are apparently founded on the same mathematical property. The one in most common use is Amsler's, and of this several kinds differing in arrangement have been constructed. The simplest form is that shown in *Fig.* 1.

A is a loaded disc, which rests on the table and serves as a fixed support for the instrument. At its centre B is an upright pin upon which turns the arm BC, to which at C is hinged the arm CD. The tracing point D can be moved in any direction over the paper. Exactly in the straight line CD is the arm E of the small wheel F whose edge rests on the paper, and whose centre is vertically below the intersection of CB and CD. When the tracing point is carried round the outline of any figure (the fixed point or support of the instrument A being external to the figure to be measured) so as

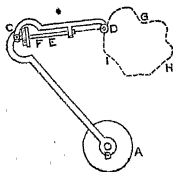



Fig. 1.

to return finally to the same point whence it started, it will be shown that the distance rolled by the edge of the wheel F multiplied by the length of the arm CD, is equal to the area of the figure bounded by the curve described by the moving point. The distance rolled by the wheel is measured by a graduated circle and vernier, not shown in the figure, complete revolutions of the wheel being indicated by a second wheel driven by an endless screw on the shaft E. It is also evident that by a proper sub-division of the wheel (depending on the length of CD) the numbers indicating the distance rolled will at once give the units of area contained within the given bounding line.

An improved form of the instrument is shown in the accompanying

Fig. 2.

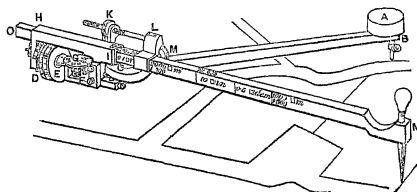



diagram (*Fig* 2). It is that termed the Polar Planimeter, and is the one now in general use.

The chief points of difference between this and the one previously described are the following:—

1st. The centre of the rolling wheel is not necessarily vertically under the point of intersection of the two movable arms, but may be at any point in or beneath the arm NO.

2nd. The arm NI (*Fig.* 2) corresponding to CD of (*Fig.* 1) may be lengthened or shortened at pleasure. The object of this will be stated presently.

The details of its construction are as follows:—

A bar BC carrying a needle point at B, and loaded disc A, is attached at the point B to the surface to be measured. At the other end C of this bar, which is cranked to escape contact with the portion GFK of the instrument in certain positions, a pair of vertical pivots are centered, so that

the bar moves freely upon them in a horizontal direction. The axes of the pivots are upon a frame which carries the calculating apparatus, consisting of a roller (E) fixed on a horizontal spindle carrying a divided drum (D), which divides the circumference of the roller into 100, and by vernier into 1000 equal portions. Upon the horizontal spindle a worm (not shown in the figure) is cut. This by a pinion (F), moves the small disc G, which is divided to register the number of complete revolutions of the roller. The frame which carries the calculating apparatus and bar described has a tubular fitting HI, in which slides, and is adjusted by the screw M, the bar ON which carries the tracing point at N. This bar ON is divided by various lines indicating different adjustments.

It is, for any one of these, moved along the tube until the corresponding line exactly co-incides with the edge I of the tubular fitting. The planimeter as ordinarily supplied is usually marked with the following scales:—

1 sq. dem.	*i. e.*,	one square decimetre.	For every rotation of the roller.
0·1 sq. ft.	,,	0·1 square foot.	
2000 sq. m. 1 : 500	,,	2000 square metres. on a scale 1 : 500.	
10 sq. in.	,,	10 square inches.	
0·5 sq. dem.	,,	0·5 sq. decimetres.	
1000 sq. m. 1 : 500.	,,	1000 square metres. on a scale 1 : 500.	

It will be sufficient to explain two of these to show the method of using them. Suppose first that the line corresponding to 0·1 square foot co-incides with the end I of the tube, and that the instrument is placed into position to measure any area. The distance traversed by the rolling wheel as measured by the two registering wheels D and G will give the area in units, each equal to one-tenth of a square foot. That is, if the wheel G registers 5 complete revolutions, and the drum and vernier D $\frac{435}{1000}$, or ·435 of a revolution, the actual area of the figure to be measured will be 5·435 × 0·1 square foot, or ·5435 square feet. Similarly for the markings 10 square inches, 1 square decimetre, 0·5 square decimetre.

The expression $\left.\begin{matrix}\text{2000 square metres}\\ 1 : 500\end{matrix}\right\}$ indicates that if employing a scale of 1 : 500, the unit of measurement being the metre, any area be laid down on paper, and the planimeter be employed to determine the area in

the usual manner, then each revolution of the rolling wheel will correspond to 2000 square metres of actual area.

Thus, supposing the same number of revolutions made as in the previous case, the area would be 5·435 × 2000 square metres, or 10,870 square metres. The remaining scale $\left.\begin{matrix}\text{1000 square metres}\\ 1 : 500\end{matrix}\right\}$ is to be understood in a similar manner.

Besides these there are usually other numbers engraved along the top of the bar. These vary in different instruments, and depend as will afterwards be seen, on the lengths of the arms BC and CN, and the distance of the wheel from the point of intersection of the movable arms. These are in the one supplied to me 20 778, 20·776, 22·130. They are employed when the fixed point is placed *within* the figure to be measured.

Method of use of the Planimeter in measuring areas. Slide the frame along the bar until the line indicating the required denomination of area is adjusted in the manner already stated. Thus if measurements are in inches, set it to the line adjacent to scale 10 square inches. Each revolution of the wheel will therefore indicate 10 square inches of area. It is then placed upon the paper in the manner shown in the engraving, the fixed and loaded point being placed if possible *outside* the figure. The reading of the instrument is then taken. Thus suppose the horizontal disc reads 8, the drum of the vertical roller 74, and the vernier 6, this will give the complete reading 8·746. The tracing point must now be moved carefully and slowly to follow the outline of the figure *from left to right*, so that the wheel may rotate in the direction corresponding to the increase of rotation as registered by the wheels, until it returns to the starting point. Suppose the reading to be now 10·625. Then the difference between 10·625 and 8·746 or 1·879 indicates the number of revolutions made by the roller, and since each revolution corresponds to an area of 10 square inches, the total area measured is 1·879 × 10 square inches, or 18·79 square inches.

The rule therefore when the fulcrum is outside the figure is—

Multiply the difference between the initial and final readings for a complete revolution by the number engraved on the bar corresponding to the particular adjustment.

If the fixed point is placed inside the figure to be measured, as must be done in large areas, (if we wish to avoid the labor of dividing it into

smaller areas, and taking the sum of these for the whole), the calculation includes the use of the figures engraved on the top of the bar. Thus suppose the adjustment is as before for inches, and that the corresponding number on the top of the bar is 22·130. This must be added to the second reading before the first reading is subtracted. Supposing the initial and final readings were the same as in the preceding case, the following would be the determination of the area.

Second reading, ...	10·625
Add number engraved corresponding to 10 square inches, ...	22·130
	32·755
Subtract the first reading, ...	8·746
	24·009
	10

Multiply by 10 (since each revolution = 10 square inches,) 240·09 square inches = area of given figure.

The rule when the fulcrum is outside the figure is :—

To the second reading, add the constant quantity engraved on the upper face of the bar, corresponding to the given adjustment, and multiply the difference between this and the initial reading, by the number of units of area corresponding to each revolution of the instrument.

When the fulcrum is placed within the figure to be measured, it will sometimes happen that the horizontal disc (which only records ten revolutions of the rolling wheel), will go through more than one revolution either forwards or backwards. In that case we must add 10 for each complete revolution, observing that if the disc passes the numbers moving forward as 8, 9, 0, 1, 2, &c., for each revolution, 10 is added to the second reading, but if backwards as 2, 1, 0, 9, &c., it must be added to the first reading (which is equivalent to the direct correction of subtracting it from the second reading). The reason of this is obvious.

I shall first of all prove the principle for the simplest case, that in which the wheel is at the intersection of two limbs of equal length, somewhat fully, as it will simplify the processes of integration, and supply the key to the more difficult cases.

Suppose QC′C to be a small portion or arc of the curve bounding the area to be measured, C and C′ being consecutive points; OB, BC the position of the arms for the first point C, OB′, B′C′, their position for the consecutive point C′. Assume OA as a fixed line of reference, and let $\angle$ COA $= \theta$, $\angle$ BOA $= \phi$, OB $=$ BC $=$ OB′ $=$ B′C′ $= a$, and CO $= r$. Then BB′ (a small arc of the circle whose radius is OB) is the space described by the extremity B of the arm OB, corresponding to CC′, the arc described by the tracing point.

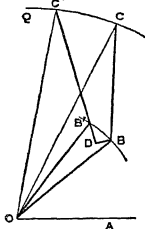



Fig. 3.

The wheel at B only moves in a plane perpendicular to BC, or B′C.′ Draw therefore BD at right angles to C′B′ meeting C′B′, or C′B′ produced in the point D.

Then since the motion BB′ is equivalent to the motion BD, (perpendicular ultimately either to BC or B′C′, if the arc CC′ is taken small enough) and the motion DB′ in the direction BC or B′C′, and that the rotation of the wheel only measures motion in the direction perpendicular to BC or B′C′, BD will ultimately be the space rolled through by the wheel as the arms OBC pass to the consecutive position OB′C′.

Also since BOB′ is the small change in the angle ϕ it may be denoted by $d\phi$ (ϕ and $d\phi$ being expressed in circular measure).

Hence arc BB′ $=$ OB $\times$ $d\phi$

$= a d\phi$

Also since BDB′ is a right angle, BDB′ may be considered to be a right-angled triangle.

$\therefore$ BD $=$ BB′ cos B′BD

$= a \cos$ B′BD . $d\phi$

$= a \cos (\pi -$ OBC$)\, d\phi$, ultimately (since OBB′ and CBD are then right angles).

$= a \cos 2$ BOC . $d\phi$

$= a \cos 2\,(\theta - \phi)\, d\phi$

Also the total space described by the wheel $=$ the sum of the elementary spaces BD

$$= \int a \cos 2\,(\theta - \phi)\, d\phi$$

Total space described by the wheel × BC

$$=\int a^2 \cos 2(\theta-\phi)\,d\phi \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1).$$

$$=\int a^2 \cos 2(\theta-\phi)\left\{d\theta - d(\theta-\phi)\right\}$$

$$=\int a^2 \cos 2(\theta-\phi)\,d\theta - \int a^2 \cos 2(\theta-\phi)\,d(\theta-\phi)$$

$$=\int a^2 \left\{2\cos^2(\theta-\phi) - 1\right\} d\theta - \int a^2 \cos 2(\theta-\phi)\,d(\theta-\phi)$$

$$=\int 2a^2 \cos^2(\theta-\phi)\,d\theta - \int a^2\,d\theta - \int a^2 \cos 2(\theta-\phi)\,d(\theta-\phi)$$

$$=\int \frac{r^2}{2}\,d\theta - \int a^2\,d\theta - \int a^2 \cos 2(\theta-\phi)\,d(\theta-\phi) \ldots\ldots\ldots (2),$$

since evidently $r = 2a\cos(\theta-\phi)$

Now for a complete revolution when the fixed point is external to the area, θ and $\theta - \phi$ return to their original values, and then by the principles of the integral calculus the second and third integrals of the expression (2) vanish, and hence

Total space described by the wheel × BC

$=\int \frac{r^2}{2}\,d\theta$ taken between the limits of θ for a complete revolution.

$=$ area of the figure.

If the fixed point is internal, θ will in one revolution increase from the initial value θ' to $\theta' + 2\pi$, and $\overline{\theta-\phi}$ return to its original value. In this case, the last integral in expression (2) only will vanish, and then the total space described by the wheel × BC

$$=\int_{\theta'}^{2\pi+\theta'} \frac{r^2}{2}\,d\theta - \int_{\theta'}^{\theta'+2\pi} a^2 d\theta$$

$=$ area of curve $- 2\pi a^2$,

or area of curve $= 2\pi a^2 +$ total space described by the wheel × BC.

In this case we see that the constant quantity $2\pi a^2$ must be added to the total space described by the wheel multiplied by BC, to give the area enclosed by the curve. This number $2\pi a^2$ may (as is usually done) be converted into revolutions, and added to the number recorded by the wheels. It then would correspond to the numbers 22·130, &c., already pointed out as engraved on the top of the bar, and is of course constant for the given length a of the bars.

Secondly. Suppose the wheel is attached at a point not in the same vertical line with the point of intersection of the arms.

Fig. 4.

Let OB, BC, OB′, B′C′ be the positions of the arms for two consecutive points C and C′ of the curve.

Let E be the point in BC giving the position of the wheel.

Draw CH, BD, EF perpendicular to B′C′.

N is the point of intersection of BC and B′C′ or of two consecutive positions of the arm BC.

EF is evidently the small arc described by the wheel during the change from the position OBC to OB′C′. Employ the same notation as in the first case, and let BE $= c$, and $\angle$ OC′C (or the angle which the radius rector makes with the small portion of the curve CC′, or ultimately with the tangent at C or C′) be denoted by χ.

Then since $\angle$ OCB $= \angle$ BOC $= \theta - \phi$, $\angle$ B′C′C $= \chi - \theta + \phi$;

also CC′ $=$ elementary arc of curve $= ds$

$\therefore$ In the right-angled triangle HCC′, CH $= ds \sin(\chi - \theta + \phi)$, whence since CH, BD, EF are all parallel,

$$\text{EF} = \text{BD} - \frac{\text{EB}}{\text{CB}}(\text{CH} - \text{BD})$$

$$= \text{BD}\left(1 + \frac{\text{EB}}{\text{CB}}\right) - \frac{\text{EB}}{\text{CB}} \cdot \text{CH}.$$

$$= \left(1 + \frac{c}{a}\right) a \cos 2(\theta - \phi)\, d\phi - \frac{c}{a} \sin(\chi - \theta + \phi)\, ds$$

$$= (a + c) \cos 2(\theta - \phi)\, d\phi - \frac{c}{a} \sin(\chi - \theta + \phi)\, ds$$

$$= (a + c) \cos 2(\theta - \phi)\, d\phi - \frac{c}{a}\left\{(\sin\chi \cos(\theta - \phi) - \cos\chi \sin(\theta - \phi)\right\} ds.$$

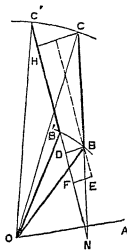
$$\text{But } \sin\chi\, ds = r \frac{d\theta}{ds} \cdot ds = r d\theta,$$

$$\text{and } \cos\chi\, ds = \frac{dr}{ds} \cdot ds = dr.$$

$$\therefore \text{EF} = (a + c)\cos 2(\theta - \phi)\, d\phi - \frac{c}{a}\left\{(r \cos(\theta - \phi)\, d\theta - \sin(\theta - \phi)\, dr,\right\}$$

also $r = 2a \cos(\theta - \phi)$

$\therefore\ dr = -2a \sin(\theta - \phi)\, d\ (\theta - \phi)$

whence $\text{EF} = (a + c)\cos 2(\theta - \phi) d\phi - 2c\cos^2(\theta - \phi) d\theta - 2c\sin^2(\theta - \phi) d(\theta - \phi)$

$$= (a + c)\cos 2(\theta-\phi)\,d\phi - 2c\cos^2(\theta-\phi)\,d\phi - 2c\cos^2(\theta-\phi)\,d(\theta-\phi)$$
$$- 2c\sin^2(\theta-\phi)\,d(\theta-\phi)$$
$$= (a + c)\cos 2(\theta-\phi)\,d\phi - c\,\{1 + \cos 2(\theta-\phi)\}\,d\phi - 2c\,d(\theta-\phi)$$
$$= a\cos 2(\theta-\phi)\,d\phi - c d\phi - 2c\,d(\theta-\phi)$$
$$= a\cos 2(\theta-\phi)\,d\phi + c d\phi - 2c\,d\theta$$

and total space described by the wheel in a complete revolution $\times$ BC

$$= a\,\Sigma\,(\mathrm{EF})$$
$$= \int a^2\cos 2(\theta-\phi)\,d\phi + \int ac\,d\phi - \int 2ac\,d\theta$$

the limits of θ and ϕ being taken to correspond to a complete revolution, in which case the integrals $\int acd\phi$ and $\int 2ac\,d\theta$ vanish, and therefore,

$$\text{the total space described} = \int a^2\cos 2(\theta-\phi)\,d\phi$$
$$= \int \frac{r^2}{2}\,d\theta, \text{ as in the previous case.}$$

The proofs in the more difficult cases will be given much more briefly.

Thirdly. Suppose the arms are unequal, and the centre of the wheel as before, at the intersection of the arms. Assume OB, BC, OB′, B′C′, as in the preceding, to be the positions of the arms for two consecutive points, OA the fixed line of reference, and let (*see Fig.* 3).

$$\angle\,\mathrm{BOA} = \phi;\ \angle\,\mathrm{COA} = \theta\ .\ \angle\,\mathrm{OCB} = \Psi$$
$$\mathrm{OB} = a : \mathrm{BC} = b,\ \mathrm{OC} = r.$$

Then elementary space described by the wheel $=$ BD $=$ BB′ cos DBB′

$$= a d\phi\cos(\theta - \phi + \Psi)$$

Hence total space described by the wheel in any finite motion $\times$ BC

$$= \int ab\cos(\theta-\phi+\Psi)\,d\phi$$
$$= \int \frac{r^2 - a^2 - b^2}{2}\,d\phi$$
$$= \int \frac{r^2}{2}\,d\theta - \int \frac{a^2+b^2}{2}\,d\theta - \int \frac{r^2-a^2-b^2}{2}\,d(\theta-\phi)\ \ldots (3).$$

We also have—

$$a\sin(\theta-\phi) = b\sin\Psi,\ \ldots\ldots\ldots\ldots (4).$$
$$\therefore\ a\cos(\theta-\phi)\,d(\theta-\phi) = b\cos\Psi\,d\Psi,\ \ldots\ldots\ldots\ldots (5)$$

$$\text{and} \int \frac{r^2-a^2-b^2}{2}\,d(\theta-\phi) = \int ab\cos(\theta-\phi+\Psi)\,d(\theta-\phi)$$
$$= ab\int\cos(\theta-\phi)\cos\Psi\,d(\theta-\phi) - ab\int\sin(\theta-\phi)\sin\Psi\,d(\theta-\phi)$$

$$= \int b^2 \cos^2 \Psi \, d\,\Psi - \int a^2 \sin^2 (\theta - \phi) \, d\,(\theta - \phi) \text{ from (4) and (5),} \ldots (6).$$

Substituting the result of (6) in (3), that expression becomes

$$\int \frac{r^2}{2} d\theta - \int \frac{a^2 + b^2}{2} d\theta - \int b^2 \cos^2 \Psi \, d\,\Psi + \int a^2 \sin^2 (\theta - \phi) \, d(\theta - \phi) \; (7).$$

which for a complete revolution, (the fixed point being external to the figure) reduces to

$$\int \frac{r^2}{2} \, d\theta \text{ (taken between the proper limits of } \theta)$$

$$= \text{area of curve} \ldots\ldots\ldots\ldots \; (8).$$

If the fixed point be within the figure, the expression (7) is equivalent to

$$\int \frac{r^2}{2} \, d\theta - \int \frac{a^2 + b^2}{2} \, d\theta - \int \frac{b^2}{2} \, d\,\Psi - \int \frac{b^2}{2} \cos 2\,\Psi \, d\,\Psi$$

$$+ \int \frac{a^2}{2} \, d\,(\theta - \phi) - \int \frac{a^2}{2} \cos 2\,(\theta - \phi) \, d\,(\theta - \phi)$$

$$= \int_{\theta'}^{2\pi + \theta'} \frac{r^2}{2} \, d\theta - \pi\,(a^2 + b^2),$$

since Ψ and $(\theta - \phi)$ return to their original values in a complete revolution,

$$= \text{area of curve} - \pi\,(a^2 + b^2) \ldots\ldots\ldots\ldots \; (9).$$

which may be interpreted in the same manner as the preceding similar case.

Fig. 5.

Lastly. Suppose that the centre of the wheel is not placed vertically below the intersection of the arm, but at any point along BC.

Let E be the position of the wheel. Then EF parallel to BD will be the elementary arc described by the wheel.

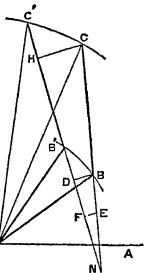
Let $BE = c$, and the other lines and angles of the figure be denoted by the same letters as in the previous case.

Draw CH perpendicular to C′B′, and let $\angle\, CC'O = \chi$.

Then $CH = CC' \sin CC'B'$

$$= ds \sin (\chi - \Psi) \ldots\ldots\ldots\ldots \; (10).$$

and $BD = a d\phi \cos (\theta - \phi + \Psi) \ldots\ldots\ldots\ldots \; (11).$

whence since EF, DB and CH are all parallel,

$$EF = BD - \frac{EB}{CB}(CH - BD),$$
$$= BD\left(1 + \frac{EB}{CB}\right) - \frac{EB}{CB} \cdot CH,$$
$$= \left(1 + \frac{c}{b}\right) a \cos(\theta - \phi + \Psi)\, d\phi - \frac{c}{b}\sin(\chi - \Psi)\, ds,$$
$$= \frac{a(b+c)}{b}\cos(\theta - \phi + \Psi)\, d\phi - \frac{c}{b}\left\{\sin\chi \cos\Psi\, ds - \cos\chi \sin\Psi\, ds\right\}$$
$$= \frac{a(b+c)}{b}\cos(\theta - \phi + \Psi)\, d\phi - \frac{c}{b}\left\{r\cos\Psi\, d\theta - \sin\Psi\, dr\right\}, \ldots\ldots(12).$$

$$\text{Again } r\cos\Psi = \frac{r^2 + b^2 - a^2}{2b} \ldots\ldots\ldots\ldots (13).$$

$$\text{and } r = b\cos\Psi + a\cos(\theta - \phi)$$
$$\therefore\ dr = -b\sin\Psi\, d\Psi - a\sin(\theta - \phi)\, d(\theta - \phi),$$
$$\text{and } \sin\Psi\, dr = -b\sin^2\Psi\, d\Psi - a\sin(\theta - \phi)\sin\Psi\, d(\theta - \phi)$$
$$= -b\sin^2\Psi\, d\Psi - \frac{a^2}{b}\sin^2(\theta - \phi)\, d(\theta - \phi) \ldots\ldots\ldots\ldots(14).$$

whence substituting (13) and (14) in (12), that expression becomes

$$\frac{a(b+c)}{b}\cos(\theta - \phi + \Psi)\, d\phi - \frac{c}{b}\left\{\frac{r^2+b^2-a^2}{2b}d\theta + b\sin^2\Psi\, d\Psi + \frac{a^2}{b}\sin^2(\theta-\phi)\, d(\theta-\phi)\right\}$$

whence the space described by the wheel during finite motion $\times$ BC

$$= \int a(b+c)\cos(\theta-\phi+\Psi)d\phi - c\int\frac{r^2+b^2-a^2}{2b}d\theta - bc\int\sin^2\Psi d\Psi - \frac{a^2c}{b}\int\sin^2(\theta-\phi)d(\theta-\phi)(15)$$

But by the preceding investigation from equations (3) and (6)

$$a\int\cos(\theta-\phi+\Psi)d\phi = \frac{1}{b}\int\frac{r^2}{2}d\theta - \int\frac{a^2+b^2}{2b}d\theta - \int b\cos^2\Psi d\Psi + \int\frac{a^2}{b}\sin^2(\theta-\phi)d(\theta-\phi).$$

Substituting this in (15), the expression becomes—

$$\frac{b+c}{b}\int\frac{r^2}{2}d\theta - \frac{b+c}{2b}\int(a^2+b^2)\, d\theta - b(b+c)\int\cos^2\Psi\, d\Psi + \frac{a^2(b+c)}{b}\int\sin^2(\theta-\phi)d(\theta-\phi)$$
$$-\frac{c}{b}\int\frac{r^2}{2}\, d\theta - \frac{c}{2b}\int(b^2-a^2)\, d\theta - bc\int\sin^2\Psi d\Psi - \frac{a^2c}{b}\int\sin^2(\theta-\phi)\, d(\theta-\phi)$$
$$= \int\frac{r^2}{2}d\theta - \int\frac{a^2+b^2}{2}d\theta - bc\int d\theta - b^2\int\cos^2\Psi d\Psi - bc\int d\Psi + a^2\int\sin^2(\theta-\phi)d(\theta-\phi).$$
$$= \int\frac{r^2}{2}\, d\theta$$ for a complete revolution when the fulcrum is within the figure,

and $= \int\frac{r^2}{2}\, d\theta - \pi(a^2 + b^2 + 2bc)$, for a complete revolution, when the fulcrum is outside the area to be measured.

J. E.

No. XLIII.

NOTES ON FLOORS IN BOMBAY.

[Vide *Plate* No. XXXVII.]

By J. H. E. Hart, Esq., C.E. *Acting Superintending Engineer, Bombay.*

In the public buildings lately constructed by the Government of Bombay, flooring as illustrated in the accompanying sheet of drawings (*Plate* XXXVII.,) has been adopted by Colonel Fuller, R.E.

The following is a brief description:—The framing of the floors generally consists of iron or teak wooden girders, resting on stone bed plates, and placed at distances apart of from 8 to 10 feet; on these girders are fixed joists of teak wood, at a distance apart of one foot, from centre to centre. Slabs of stone, bricks, or board, with concrete thereon, form the body of the floor; and on this are laid boards, Minton tiles or Mosaic work as a surface.

Fig. 1 shows the general arrangement of girders and joists in plan.

Fig. 2 is a cross section, taken on line AB in *Fig.* 1, of a floor composed of iron girders and rectangular wooden joists, with concrete between. The concrete is supported by short boards, fixed on fillets between the joists, and the floor-surface is formed of Minton tiles, laid in Portland cement, on the concrete. The boards are either bevelled and lapped, or tongued, grooved and beaded.

Fig. 2A is a cross section of the above, on line CD, to an enlarged scale.

This description of floor is used in the New Secretariat Building; it is finished off underneath as a ceiling, by boxing the iron girders, and chamfering the joists and surfaces.

Fig. 3 is a similar arrangement of girders and joists, but in which the concrete is supported on slabs of Porebunder stone, $2\frac{1}{2}$ inches thick, laid on the top of the joists.

Fig. 3A is a cross section of the same to a large scale. This floor is largely used in all the Public Buildings, and is finished off below by painting the under surface of the slabs white, and the wood-work a suitable light color.

A similar form of floor is used in some buildings having, however, the girders of teak wood, instead of iron.

Fig. 4 is an arrangement of wooden girders and wedge-shaped joists, between which bricks-on-edge are jammed by the shape of the joists. On these concrete; and teak boarding, tongued and grooved, forms the floor surface. The ceiling below is formed by teak planking, with bevelled edges, which is varnished.

Fig. 4A is an enlarged cross section of the above, on line CD. This class of floor is largely used in the new Public Works and Post Offices, and in the Native General Hospital.

Fig. 5 is a cross section of a flooring, used in the Sassoon Mechanics Institution, formed of brick arching, concrete, and Minton tiles, on iron girders. *Fig.* 5A is a section of the same at right angles to the girders, and line of arching.

The ceiling below is formed of ceiling joists and painted boarding.

Another class of flooring, not shown in the drawings, is similar to that represented in *Fig.* 4, except that concrete (kept in position while setting by temporary boards) is used, instead of bricks-on-edge. The floor surface is formed of Minton tiles, and the ceiling is of varnished teak planking. This construction was adopted in the Elphinstone College Buildings.

The concrete used in the floors is formed of equal parts of Porebunder, chips and mortar, the mortar being made with equal parts of Salsette lime, and sand, ground in a bullock mill twice, at an interval of four days, the grinding being continued for 2 hours each time.

The Minton tiles are the encaustic tiles, made under patent in England.

The Mosaic work floor surface has been recently introduced as an experiment into Bombay by an Italian firm, and is laid down in the New Post Office. It is formed by small cubical pieces of marble, of various colors, embedded in a matrix of cement.

The cubes are arranged to form patterns and are afterwards rolled in,

the surface being then polished. The cost is from Rs. 1-8 to Rs. 2 per square foot.

The effect is very good, but its lasting powers remain to be tested.

The following is a Table of the dimensions of the various parts of the above floors:—

Names of buildings.	Girders 10 feet apart.		Joists 1 foot apart.	
	Span in feet.	Scantling in inches.	Span in feet.	Scantling in inches.
		b. d.		b. d.
New Secretariat,	25 to 26·5	12″ × 18″	9 to 11	3″ × 8″
The Iron girders are as shown in drawings, the span being 30 feet.			20	3½″ × 11″
			25	4″ × 12″
Public Works Offices,	19·5	10″ × 16″	10	3″ × 8″
	23	12″ × 18″		
Post Office,	20 to 23	12″ × 18″	7½ to 10	3″ × 8″
	25 to 27	13″ × 20″	10 „ 11½	3½″ × 9″
	32	14″ × 22″	15½ „ 19¼	4″ × 10″
Native General Hospital,	18 to 20	10″ × 18″	7 to 4½	3″ × 7″
	21 to 24	12″ × 18″		

The weights of these floors and of the materials composing them are as follows:—

Iron girders, flanges, ... 4 L-irons 3″ × 3″ × ½″
2 plates 7½″ × ½″
Web 22″ × ½″

Span 30 feet; length 32 feet; weight 27¼ cwt.

Teak wood, ...	42	lbs. per cubic foot.
Porebunder slabs 2½ inches thick, ..	136	„ „
Brick, ...	102·3	„ „
Concrete, ...	95	„ „
Minton tiles ½″, ...	147	„ „
Structural weight of floors from	80 to 90	„ „
Casual weight, a crowd of people,	84 to 90	„ „

The component parts of the above "structural weight" are as follows:—

Iron girders,	9·5 to 8·1 lbs., per square foot of floor.			
Wooden do., 12′ × 18″ average,	6·3	"	"	"
Joists 3″ × 8″, Average,	7·0	"	"	"
Porebunder slabs, 2½ inches thick,	28·4	"	"	"
Concrete 3″ thick,	37·0	"	"	"
Minton tiles, ..	6 2	"	"	"
Boarding 1″ thick,	3 5	"	"	"
Fillets 2″ × 1″,	1·2	"	"	"
Bricks, ...	44 to 54	"	"	"

The following is the cost in Bombay of the several items of work in floors of about 24 feet span per 100 superficial feet of flooring.

		RS. A. P.		RS.
2·04 c. ft.	Basalt bed plates or templates,	@ 2 0 0	per c. ft., .	4·08
5·90 cwt.	Wrought-Iron girders,	@ 13 0 0	" cwt., .	76 70
12·24 c. ft.	Teak girders,	@ 3 12 0	" c. ft., .	45·20
17·63 "	" joist,	@ 3 8 0	" " .	61·80
·70 "	" wall plates,	@ 3 0 0	" " .	2·10
100·00 s. ft.	Slabs of Porebunder stone,	@ 120 0 0	per 100 s. f., .	120·00
25 to 33 c. ft.	Concrete, 3″ to 4″ thick,	@ 130 0 0	" " c. ft, .	34 to 45
100 s. ft.	Minton tiles (6s. pattern),	@ 70 0 0	" 100 No., .	70·00

Note.—The price of concrete includes consolidation, and upper surface of plaster of fine chunam.

BOMBAY,
28th March, 1872.

J. H. E. H.

No. XLIV.

ON THE MODULI OF ELASTICITY AND ON DEFLEXION.

By Lieut. Allan Cunningham, R.E., *Hony. Fellow of King's College, London, and Offg. Professor of Mathematics, Thomason C. E. College, Roorkee, N. W. P.*

This paper is an attempt to harmonize several sets of formulæ and tables relating to elasticity and deflection, which without some explanation appear discordant: as a matter of fact the want of this explanation in received text-books proves a matter of considerable confusion to Students.

The quantity termed "co-efficient" or "modulus of elasticity," and denoted by the letter E., is indifferently applied by many writers to three distinct constants expressing three distinct physical properties of any one material.

They are all three really only the quantitative expressions of Hooke's law of elasticity, viz., "*ut tensio sic vis,*" *i.e.*, that *stress is proportional to strain* within certain limits (called the limits of elasticity), under the three principal applications of external force, viz., Extending, Compressing, and Transverse.

The values of E corresponding to these three different applications of external force should be derived from experiments on loads applied in each of these three manners.

These values of E may be distinguished as follows :—

E_t derived from experiments on extension under tension.

E_c ,, ,, contraction under compression.

E_d ,, ,, deflexion under transverse load.

The practical usefulness of this paper is in pointing out the numerical relations between these quantities, which are important for the reason that, in *most Treatises* on *Higher Applied Mechanics*, E_t is the quantity used *throughout all formulæ* and investigations, but the numerical *value of E_d is alone accessible for many materials,* (this is certainly the case with Indian woods,) and *the particular E_d of different tables* is *different.*

Determination of E_t *and* E_c.

Extension and Compression being both direct in action and normal to the transverse sections of the material strained, the quantities E_t and E_c are derivable from the same formula, thus,

If p = intensity of stress in lbs. per square inch of transverse section·
l = length of piece to be experimented on in inches.
δl = strain, (*i.e.*, extension or contraction) produced by the stress p in inches.

Then by Hooke's law of elasticity,

$\delta l : l = p$: a constant quantity (provided the intensity of strain $\delta l \div l$ does not exceed the limit of elasticity). This constant is what is denoted by E.

$$\therefore E = \frac{p}{\delta l} . l$$

E is of course either E_t or E_c according as the strain is an extension or contraction.

It is a remarkable thing that the strains, *i.e.*, extensions or contractions under equal loads are for many materials approximately equal, and that consequently E_t and E_c are approximately equal. It seems to be generally accepted in the profession that for practical purposes the values of E_t and E_c may be assumed to be equal in building materials. In fact all the present treatment of Higher Applied Mechanics depends on one consequence of the above, viz., that the neutral surface of a beam under transverse load passes through the centre of gravity of every section.

It is especially to be noticed that the direct experiments necessary for the determination of E_t and E_c, (and more particularly of E_c) are very expensive and difficult. But on the assumption that they are equal, the value of E, (*i.e.*, E_t or E_c) may be determined indirectly through experiments on the deflexion of beams which are far less expensive and easier of execution than those on direct extension and contraction.

A *straight* beam of *uniform rectangular* section is *placed* on two supports *on same level*, and loaded *at its middle.*

Let l = clear distance between supports in inches.

L = the same in feet. $\therefore L = l \div 12$

b = breadth of beam in inches. d = depth of beam in inches.

W = total load applied at middle in lbs.

δ = deflection at middle *produced by* W in inches, (*i.e.*, neglecting the weight of beam).

Then it is proved by theoretical writers* (provided the limit of elasticity is not exceeded) on the three following assumptions.—

(1). Hooke's law of elasticity.

(2). That the neutral surface passes through the centre of gravity of every cross section (*i.e.*, that $E_t = E_c$)

(3). That the total deflexion δ is small.

$$\text{Then } \delta = \frac{W\,l^3}{4E_t\,bd^3}, \text{ whence } E_t = \frac{W\,l^3}{4\;bd^3\;\delta}$$

From this equation, E may be calculated if δ be observed.

On the co-efficient E_d.

The most important writer, both as experimentalist and theorist on this quantity is Peter H. Barlow. The experimenters on the Indian woods seem all to have followed his method, and have deduced E_d (not E_t which has been already indicated as the most useful) from their experiments.

Barlow's chief merit is as an experimentalist: in his attempt to construct formulæ theoretically for cases not experimented on, he is not so successful, and has made at least one serious mistake, which has unfortunately been copied into some of the Indian text-books.

His method is as follows†. He investigates *theoretically* the deflexion of *a straight horizontal* beam *of uniform rectangular* section, under the following four conditions :—

Case (1). As a cantilever loaded at free end.

„ (2). „ cantilever uniformly loaded.

„ (3). „ beam supported at both ends loaded at middle.

* *See* Rankine's Manual of Civil Engineering, 6th Ed., Art. 169.

† Treatise on Strength of Timber, &c., by Peter Barlow. London 1845.

Case (4). As a beam supported at both ends, uniformly loaded.

He endeavors to establish that in each case the following quantity $\frac{l^3 W}{bd^3 \delta}$ is a constant quantity depending only on the material *in each case* within the limits of elasticity.

Case (1). Assuming only (1). Hooke's law of elasticity.

" " (2). That the deflexion δ is very small.

He proceeds to establish the differential equation of the deflexion curve, or "elastic curve," assumed by the originally horizontal lines of the beam, and after integration by a method analogous to that still employed by all writers on physics, establishes the result $\frac{l^3 W}{3 \delta}$= a constant quantity, which he there denotes by E, (*i.e.*, E_d,) depending only on the material.

He also establishes the same result by a circuitous process of approximation for the benefit of readers not acquainted with the integral calculus.

Case (2). By the same circuitous process he establishes that in this case $\frac{3}{8} \cdot \frac{l^3 W}{3\delta} = E_d$, *the same constant* as in Case 1.

Case (3). He endeavors to establish this case *from general considerations* without reconsidering the form of the deflexion curve, and herein he decidedly fails. The writer considers Barlow's line of argument in this case (from general considerations) an unsafe one, requiring very great caution, as it involves several *mere assertions* (unproved) as premisses.

His principal premiss is that this case is similar as regards stress (called by him strain) to that of the same beam supported freely at its middle, with the projecting free ends loaded each with half the load. His inference is that the element of deflexion, and consequently also the whole deflexion, in the former case are respectively double of the element of deflexion and of the whole deflexion in the latter.

This inference is (in the writers' opinion) *wrongly drawn from the premiss.* The inference naturally deducible appears (to the writer) to be that the two quantities, viz., the element of deflexion and whole deflexion are respectively equal in the two cases.

This error of course vitiates the result which Barlow deduces, viz., $\frac{1}{32} \cdot \frac{l^3 W}{3\delta} = E_d$, *the same constant as in Case* I.

The result logically deducible is (in the writer's opinion) that $\frac{1}{16}$ $\frac{l^3 W}{3\delta} \cdot = E_d$ the same constant as in Case I. This mistake appears to

have been discovered by the author after the publication of the edition of 1845: the intermediate editions are not accessible to the writer, but at any rate, in the 6th edition in 1867, the correct inference, viz., that $\frac{1}{16} \cdot \frac{l^3 W}{3\delta} = E_d$ *the same constant* as in Case 1, is drawn *from the very same line of argument*, reprinted almost verbatim, but without any remark as to the reason of change from the 1845 edition.

Case (4). By a repetition of the processes as in Case (1), he shows that the deflexion at the middle in this case is $\frac{5}{8}$ of the deflexion at the middle in Case (3), and consequently that $\frac{5}{8} \times \frac{1}{32} \frac{l^3 W}{3\delta} = E$, *the same constant as in* Case (1), according to the edition of 1845, and that $\frac{5}{8} \times \frac{1}{16} \times \frac{l^3 W}{3\delta} = E$, the same constant as in Case (1), according to the last edition (1867.

The four preceding results were obtained for beams of the same breadth and depth.

He afterwards establishes from the same two assumptions as before, that $E \propto \frac{1}{bd^3}$, so that his four formulæ become after rejecting for simplicity's sake the factor 3.

Case (1). $\frac{l^3 W}{bd^3\delta}$ = a constant quantity.

" (2). $\frac{3}{8} \cdot \frac{l^3 W}{bd^3\delta}$ = a constant quantity.

" (3). $\frac{1}{32}$ of, or $\frac{1}{16}$ of $\frac{l^3 W}{bd^3\delta}$ = a constant quantity.

" (4). $\frac{5}{8} \times \frac{1}{32}$ of, or $\frac{5}{8} \times \frac{1}{16}$ of $\frac{l^3 W}{bd^3\delta}$ = a constant quantity.

This constant quantity, *the same for all the formulæ* (which is evidently *three times* that used in the investigation) he proposes to denote by E (*i.e.* E_d).

Having established the four preceding formulæ on theoretical grounds, he proceeds to test *one of them* experimentally: the one chosen was Case (3), viz., that $\frac{l^3 W}{32\, bd^3\delta}$ and consequently $\frac{l^3 W}{bd^3\delta}$ a constant quantity.

This case was no doubt chosen in consequence of the greater facility of performing the experiment (on a beam freely supported at the ends, and loaded at its middle) than in the other three cases.

The result was that from a very large series of experiments, this for-

mula (taken by itself) proved correct; that is to say, it proved to be true that the quantity $\frac{l^3 W}{bd^3\delta_d}$ = a constant quantity depending only on the nature of the material.

Up to this point, it may therefore be considered to have been established by Barlow, *both theoretically and experimentally*, that in his Case (3) the quantity $\frac{l^3 W}{bd^3\delta}$ is a constant quantity depending only on the material, and that the equation $\frac{l^3 W}{bd^3\delta}$ = a constant, is really the expression of a physical law. No experiments are recorded on the other three cases, so that no perimental test of the *comparative* correctness of the four numerical co-efficients 1, $\frac{3}{8}$, $\frac{1}{32}$, $\frac{5}{8} \times \frac{1}{32}$ was established. It has already been pointed out that these should be as 1: $\frac{3}{8}$: $\frac{1}{16}$: $\frac{5}{8} \times \frac{1}{16}$, as in the latest edition.

It should now be noticed that the result established, both theoretically and *experimentally* by Barlow for his Case (3) that $\frac{l^3 W}{bd^3\delta}$ = a constant quantity, depending only on the material is consonant with that obtained on theoretical grounds previously, viz., that *in this same case* of a straight horizontal beam of uniform rectangular section supported freely at both ends and loaded at the middle $\frac{l^3 W}{4\, bd^3\delta} = E_t$, which is of course a constant for the material.

The essential difference in the two modes of investigation is that Barlow makes no hypothesis as to the position of the neutral axis, whereas writers who use E_t usually make the additional hypothesis that $E_t = E_c$ which involves the neutral axis passing through the centre of gravity of each cross section.

Determination of E_d.

It has been observed that experiments on deflexion of beams are far more easily conducted than those for the direct determination of E_t and E_c.

Most of the recorded values of E_d have been determined from experiments *on the deflexion at the middle* of *straight horizontal* beams *of uniform rectangular section freely supported at both ends* and *loaded at the middle*, only in consequence of the comparative ease and inexpensiveness of experiments so arranged.

Unfortunately, however, the recorded values of E_d have been *calculated* by different experimenters from different formulæ, so that although actually expressing *the same physical property*, viz., that $\frac{l^3W}{bd^3\delta}$ is a constant quantity for each material, they differ greatly numerically according to the units of measure used by different experimenters, and *care is required* in using tables of E (or E_d) *in observing the units of measure* intended.

It is obvious that since $\frac{l^3W}{bd^3\delta}$ is a constant quantity, therefore also $\frac{l^3W}{bd^3\delta}\times$ (any numerical ratio) is also a constant quantity.

Different numerical multipliers have been chosen by different writers, and sometimes even by the same writer in one book, so that $\frac{l^3W}{bd^3\delta}\times$ (some numerical ratio chosen by the writer) has been tabulated as E, (*i.e.*, E_d) by different writers.

The principal *tabulated* values of E_d are as follows :—

N.B.—A comparison of each with what is styled in this paper the Roorkee E_d (*vide* para. 5), *which is most largely used in India* is also given.

(1). In Barlow's original theoretical investigation of 1826 and 1845,

$$E_d = \frac{1}{32}\cdot\frac{l^3W}{3\delta} \text{ also } = \frac{1}{32}\cdot\frac{l^3W}{3bd^3\delta} = 18 \times \text{Roorkee } E_d.$$

This is of little practical importance as it is not used in tables.

(2). In Barlow's *first* tables.

"Essay on Strength and Stress of Timber," 3rd Edition, 1826.

"Treatise on Strength of Timber, &c." New Edition, 1845, (Art 61).

Also in some Indian Tables.

"Gleanings of Science," May and August 1829, Vol. I. (Experiments by Captain H. C. Baker). Calcutta 1829.

* "Scantlings of Timbers for Roofs," by Peter Keay. Roorkee, 1865, *vide* Tables I to IV.

"Scantlings of Timbers for Roofs," by Ensign Peter Keay, *vide* Tables I to IV. 2nd Edition. Roorkee, 1872.

$$E_d = \frac{l^3W}{bd^3\delta} = 1728 \times \text{Roorkee } E_d.$$

This might be called "Barlow's first E_d."

(3). In Barlow's four formulæ (Art. 103), and in the tables (Art. 104) of the

"Treatise on Strength of Timber, &c.," 1845.

* The numerical quantity *actually tabulated* is called 32 E and said to be equal to $\frac{l^3W}{bd^3\delta}$ which is the same as the quantity E_d in Para. (2).

$$E_d = \frac{1}{32} \frac{l^3 W}{bd^3 \delta} = 54 \times \text{Roorkee } E_d.$$

This might be called "Barlow's second E_d."

(4). In the latest editions of Barlow's works

"Treatise on Strength of Timber, &c." 1867.

and in some Indian Papers—

"Professional Papers on Indian Engineering" Vol. VI., Roorkee 1869. Paper No. CCXIV "Experiment on Dharwar Timbers," by J. H. E. Hart, Esq.

$$E_d = \frac{1}{16} \cdot \frac{l^3 W}{bd^3 \delta} = 108 \times \text{Roorkee } E_d.$$

This might be called "Barlow's third E_d"

(5). In some of the Indian Tables—

"Description and Strength of Indian and Burman Timbers," by Conductor T. W. Skinner. Madras, 1862.

"Professional Papers on Indian Engineering" Vol. I., Roorkee, 1863. Paper XXVII., "Scantlings of Timbers, Mysore," by Major R. H. Sankey, R.E.

Thomason C. E. College Manual, No. II., "Strength of Materials," 5th Ed., Roorkee 1869.

"Roorkee Treatise on Civil Engineering in India," by Major J. G. Medley, R.E. 2nd Edition. Roorkee 1869.

"Scantlings of Timber for Roofs," by Ensign P. Keay, 2nd Edition, Roorkee 1872.

"Professional Papers on Indian Engineering" 2nd Series, Vol. I., Paper XL. "Indian Timber Trees, by Major A. M. Lang, R.E.

$$E_d = \frac{L^3 W}{bd^3 \delta} \text{ the "Roorkee" } E_d$$

N.B.—This co-efficient being used in the Thomason Civil Engineering College text-books might be called the Roorkee E_d. For practical calculations it is very convenient on account of its being much smaller numerically than the E_d of other tables.

Comparison of E_d *with* E_t *and* E_c.

As Barlow's theory and experiment are *the source of all the determinations of* E_d, the following comparison of E_d with E_t and E_c will be made by comparing his four deflexion formulæ (Art. 103 of his "Treatise on Strength of Timber," &c), *after introducing the correction explained above* with the formulæ for deflexion (*under the same circumstances*) which involve E_t.

It will be remembered that it is assumed that $E_t = E_c$ practically.

The results of comparison are given in the table below.

COMPARISON OF E_d AND E_t.

Case.	Conditions.		Barlow's Deflexion Formulæ, only applicable to solid, straight, uniform rectangular beams.		Deflexion formulæ for solid, straight, uniform rectangular beams from Rankine's Manual of Civil Engineering 6th edition, 1870, Art 169
	Support.	Load.	Original as in Edition 1815.	Corrected as in Edition 1867.	
1	Fixed at one end,	At free end,	$\delta = \frac{l^3 W}{E_d . bd^3}$	$\delta = \frac{l^3 W}{E_d \ bd^3}$	$\delta = 4 . \frac{l^3 W}{E_t . bd^3}$
2	Fixed at one end,	Uniform over length,	$\delta = \frac{3}{8} . \frac{l^3 W}{E_d . bd^3}$	$\delta = \frac{3}{8} . \frac{l^3 W}{E_d . bd^3}$	$\delta = \frac{3}{2} . \frac{l^3 W}{E_t \ bd^3}$
3	Supported at both ends,	At middle,	$\delta = \frac{1}{32} . \frac{l^3 W}{E_d . bd^3}$	$\delta = \frac{1}{16} . \frac{l^3 W}{E_d . bd^3}$	$\delta = \frac{1}{4} . \frac{l^3 W}{E_t . bd^3}$
4	Supported at both ends,	Uniform over length,	$\delta = \frac{5}{8} . \frac{1}{32} . \frac{l^3 W}{E_d . bd^3}$	$\delta = \frac{5}{8} . \frac{1}{16} . \frac{W}{E_d . bd^3}$	$\delta = \frac{5}{32} . \frac{l^3 W}{E_t . bd^3}$

It will be observed that Barlow's four formulæ are *after correction, as in the latest edition*, (1867), perfectly accordant with those involving E_t, and that $E_t = 4 \times E_d$ of the formulæ of that edition.

N.B.—This E_d is that derived by experiment from the formula $E_d = \frac{l^3 W}{16 \, bd^3 \delta}$ styled above "Barlow's third" E_d.

Therefore $E_t = 4 \times (108 \times \text{Roorkee } E_d)$.

$= 432 \times \text{Roorkee } E_d$.

Reciprocal form of E_d.

A modified form of the reciprocal of this co-efficient was introduced by Tredgold (Elementary Principles of Carpentry, Ed. 1853), which is specially suited to Carpentry.

It was considered by Tredgold that timbers used in carpentry should have as a maximum deflection $\frac{1}{480}$ of their clear span (equivalent to a deflection *in inches* of $\frac{1}{40}$ of clear span in feet), *i.e.*, $\delta = \frac{l}{480} = \frac{L}{40}$. Since for straight horizontal beams of uniform rectangular section, loaded at the middle $\frac{L^3 W}{bd^3 \delta}$ = a constant quantity, therefore also $\frac{40 \, bd^3 \delta}{L^3 W}$ is a constant quantity (Tredgold denotes it by a, and has tabulated its value

calculated from this formula, $a = \frac{40\, bd^3\, \delta}{L^3\, W}$ for most timber woods used in England).

This form of co-efficient is specially *convenient* in carpentry *if the rate of deflection of* $\delta = \frac{L}{40}$ *be the one decided on as a maximum,* (but not otherwise), for substituting it in the formula there results the following formula very convenient for practical use, $bd^3 = a \,.\, L^2 W$.

This formula is of course applicable only to *straight horizontal* beams *of uniform rectangular section.*

Tredgold gives the modifications of it for Barlow's four cases correctly, and also for cylindrical beams.

This co-efficient which may perhaps be called Tredgold's co-efficient has been calculated (in preference to E_d) by some of the Indian experimentalists.

"Notes and Experiments on the Stone and Timber of the Gwalior Territory" by Major Alexander Cunningham, B.E. Roorkee, 1853.

Tredgold's co-efficient is denoted in this by S.

"Professional Papers on Indian Engineering" (Second Series,) Vol. I., Paper XLVIII., "Experiments no Andaman Woods," by J. Bennett, C.E., Roorkee, 1872.

$$\text{Since } a = \frac{40\, bd^3\, \delta}{L^3 W} = \frac{40}{(\text{the Roorkee})\ E_d}$$

$$\therefore \text{ the Roorkee } E_d = \frac{40}{a}$$

$$\text{And } E_t = 432 \times \frac{40}{a} = 17280 \times \frac{1}{a}$$

Tredgold introduces another modification of the reciprocal form of E_d, intended to simplify the formulæ for cantilevers. Theory indicates that it should be $16 \times a$: he denotes it by b. Thus Tredgold's $b = 16 \times$ Tredgolds a (theoretically). Its use is evidently very limited, as cantilevers are not much used. Very few direct experiments are recorded by him, and the results are irregular, (as he acknowledges), probably in consequence of the early experimenters not foreseeing that unless the manner of fixation was quite similar in all experiments, the results could not be expected to be numerically accordant: thus some of the cantilevers experimented on were *fixed* not at the point of support, but *at some little distance from it.*

The term "fixed at one end" is *now* understood to mean that the neutral axis of the cantilever is immoveably *fixed in direction at the point of support.* Experiments in which this condition was not complied with

are useless for determining b directly. From the irregularity of the values of b, obtained from direct experiment the writer considers it preferable to use its theoretical value $b = 16 \times a$.

Remarks on Barlow's and Tredgold's Formulæ.

It is to be observed that the utility of Barlow's four formulæ (even when corrected) and of Tredgold's formulæ is *greatly limited* by their not containing any factors to suit them to *other forms of cross section*, and to *other distributions of load* than those which were considered in the investigation, viz., solid *straight horizontal* beams *of uniform rectangular section*, and of circular section (in Tredgold's). General formulæ *applicable to any case whatever* are given in Art., 169 of Rankine's "Manual of Civil Engineering," 6th edition, 1870, and somewhat more fully in Art. 300 to 304 of Rankines' "Manual of Applied Mechanics," 3rd edition, 1864.

As these formulæ in their general form involve several integrations, they are certainly somewhat difficult of application, but to meet the wants of the practical man (*i.e.*, to save the necessity of this labor) a table *of the result* of integration is given for thirteen cases, most likely to occur in practice, so that for these cases they are easily applied. These formulæ involve E_t, the modulus of direct tensile elasticity.

The influence of Barlow's writings, which were followed by Tredgold, has been very great in India so that unfortunately the value of E_d or of its modified reciprocal a is the only co-efficient of elasticity usually accessible for Indian woods.

The relations established in this paper, viz.,

Modulus of tensile elasticity $E_t = \frac{1}{4} \times$ "Barlow's first" E_d.
$= 8 \times$ "Barlow's second" E_d.
$= 4 \times$ "Barlow's third" E_d.
$= 432 \times$ "the Roorkee" E_d.
$= \frac{17280}{\text{Tredgold's co-efficient } a}$.

will enable the modern English formulæ of Higher Applied Mechanics to be applied to Indian practice.

It is to be regretted that the number of experiments recorded on the Indian woods are so few.

No. XLV.

THE MOUNTAIN TRAMWAY.

(Vide *Plates* Nos. XXXVIII., XXXIX., *and* XL.)

A paper introducing to public notice several devices by which the water-power of the mountain streams can be utilized as a propulsive power, on inclined Tramways. BY *the late* WILLIAM SANDERSON, C.E.

Introduction.—The project for the application of the invention styled the hydraulic propeller on mountain tramways to the outer Himalaya—is recommended as a substitute for heavy and expensive Railways.

The mountain tramway, too slight for the steam locomotive, was designed (previous to the above-named invention) especially for the utilization of the water power of mountain streams, and for winding up the valley slopes without disturbing the surface where road making would cause landslips; its carrying powers under ordinary means of traction are very low, and it appeared unadvisable to construct a tramway on which so small a load could be carried, till the idea of the troughed channel and the water-wheel suspended from the car, permitting the repetition of the passing load, occurred and solved the problem.

This light tramway without the channel would be a valuable adjunct to the Ganges Canal, laid on its banks and worked by its water falls, with rope traction, or propulsion by atmospheric pressure.

A Railway has already been projected passing Roorkee, and following the canal bank to Hurdwar, which will involve large outlay for bridging the several mountain torrent beds; it is suggested that the design for the mountain tramway be adapted in its stead.

In the consideration of the best means of applying a retarding and arresting power to the car on mountain tramway, the idea of a new form

of steam carriage road for the plains, occurred, whereon the friction roller brake can be applied, so as to remove the necessity for the ponderous locomotive, and the concave wheel tires.

Reference is made to the water power of the doabs, and of the highlands of Central India—of the value of the water power in India there can be no doubt, and the invention here introduced to public notice has given occasion for general suggestions.

Reviewing the History of Railways, as far back as the early part of the 17th century, wooden tramways were used in the Collieries in Northumberland, carrying two to three tons upon small flanged wheels; but little coal was then worked except for domestic use. A hundred years or more later, Iron was produced in large abundance, and a Northumbrian introduced the edge rail of cast iron, spiked to a plug in a stone sleeper, and then men began to look for more powerful traction than animal power, but it was not till 1825 that the locomotive was ventured upon, and a new developing force gave an acceleration to the advancement of manufactures, and to such an enormous extension of steam power, that the very small water-power the country had made use of was overlooked. Steam power was adopted by the nations of Europe, generally, with similar, though smaller results.

In India although there is a scarcity of water power, away from the mountains, steam has not been so generally introduced by the directors of labor in official departments; but those dependent on their own resources, as the Contractors on our Railways, Planters, Manufacturers and others, have wisely availed themselves of steam power, and have been to a slight extent imitated by the departments. But so entirely has the English mind been taken up with the idea of extending steam power, that steam machinery is employed at Roorkee on the Ganges Canal in which a 30,000 H. P. is running to waste, and even when workshops have been established by untrammelled Englishmen, as on the mountain slopes over the Dhoon west of the Jumna, steam power has been adopted within a few miles of a large water power. Now that the extension of the Railway system in the plains has been secured, attention may be drawn to the outer slopes of the Himalayas between the Sutlej and Nepal, an area of 20,000 square miles containing numerous vallies, culturable plateaus, extensive mineral deposits, iron works, and tea plantations.

Railways to bear ponderous locomotives and trains are too costly for the hill country; even in the plains, in those districts where population and natural resources are scarce, the cost must tend to retard the extension of Railways, except where there are military and political requirements to warrant large expenditure on lines through districts without commerce.

The utmost possible reduction of the cost of Railways in the plains will not bring it low enough for the hill country: ordinary Railway works cost five times as much in the hills as in the plains, and the lowest safe estimate for the latter being £2,500, in the former it is £12,500 per mile; and in addition to this great cost, there is a further obstacle to the construction of permanent Railways for heavy running loads, in the liability to landslips which arises from the disturbance by road making, of the surface of mountain slopes.

To return to water power in India generally, admitting its scarcity over vast areas, and the almost universal necessity for the steam locomotive on Railways, and the steam engine for the purposes of the manufacturer; it must be noticed, that in the rivers rising in the Highlands of the Peninsula and running eastwards, and in those rising in Central India, there is contained an available water power for use as a tractive force—or for manufactory machinery. This is however merely suggestive, the present object is especially to note the value of the several streams flowing out the Himalayas (varying in capacity from river currents to the smallest rills,) as a motive power, to work tramways penetrating the hill country: which power may be applied in different modes.

First.—By rope traction by stationary engines acted upon by the mountain streams; the friction of ropes to convey their power to the carriages would necessitate the fixing of a water wheel and winding machinery at four mile distances. Rope traction could be adopted on the light mountain tramway by placing the cars of a train separately, 100 feet apart attached by a rope—the load being thus spread over the line, say 10 cars of 5 tons each. The same stream conveyed in an artificial channel on the hill side parallel to the line would be available at each winding apparatus, if conducted at a gradient less than that of the tramway to the next station where a fall should be provided.

Second.—By the use of condensers: by the water worked Stationary Engine, air may be forced into hollow metal spheres or air reservoirs, a pair of which being placed on the tramway car in conjunction with a pair

of cylinders and pistons, by mechanical contrivance alternate action may be obtained on the piston; or a pair of reservoirs may have alternate action on one cylinder of 40 strokes per minute, which with a driver of 3 feet diameter would give five miles an hour.

Third.—The same fixed Stationary Engine might be made to coil India rubber or other elastic bands on spindles, which being placed on a car specially constructed, (with the bands attached to suitable machinery, and left to uncoil,) would become propellers. The use of elastic bands tightly coiled by machinery, then placed on cars, and giving motive power by uncoiling, is an American invention; the cost of winding the bands by steam machinery was found to be too great, and this mode of propulsion was abandoned after a short trial at New York.

Rope traction may be worked over the summit of an incline if not too long. The air engine is suggested also for short inclines leaving the water channel. The elastic bands not being of great weight, a sufficient number may be carried for 10 miles.

There are still other methods of applying the water power of mountain streams to the working of tramways.

One is the "Atmospheric Railway" principle which is more than two centuries old. The idea, M. Papin's, was not worked out till after the birth of steam power; it is still in use between Kingstown and Dalkey. The principal of the apparatus is atmospheric pressure through a tube laid continuously between the rails, having on the upper face a longitudinal slit, through which an arm attached to the Railway car, passes, and within the tube is attached to a piston fitting the inside. The slit is provided with a lip which the compressed air in its passage behind the piston closes, the end of the tube is left open, and the air drawn out by machine worked air pumps. Nothing could be more easily arranged than a water worked engine to exhaust the tube of air, in front of the advancing piston attached to the car.

The next is the most simple arrangement that can be made, the least costly both in way and rolling stock: it is best described in the the Specification of Invention styled the

HYDRAULIC PROPELLER ON MOUNTAIN TRAMWAY.

This Invention consists in the first place of an ordinary water wheel of any form, whether an exposed or boxed wheel, revolved by water flow-

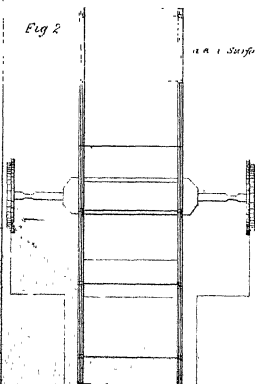
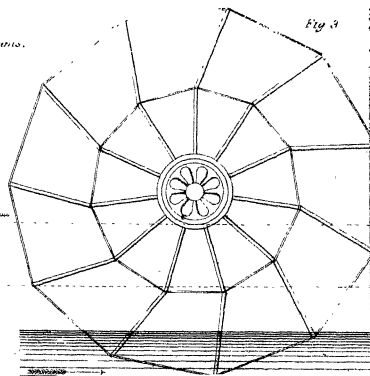
ing in a channel especially constructed, by which vertical revolution can be communicated to a pair of wheels running on rails or trams, and ascending an incline of 1 in 100 to 1 in 10. The dimensions of the water-wheel may vary according to the water power available, or to the traffic requirement; as a general rule, the diameter of the water-wheel should be six times that of the running wheels. The dimensions fixed upon for the drawings accompanying this specification are—9 feet diameter of water-wheel, and 18 inches the diameter of running wheels.

The shaft or axle of the water-wheel must extend over the trams, and for an especial reason these are placed 6 feet apart. The axle to be of steel bar $1\frac{1}{2}$ inches square, and to have a running wheel affixed to each end of cast-iron 18 inches in diameter, with a wrought-iron inner flange, projecting an inch over the tyre. The wooden nave to be fitted on the middle of the axle, to be 2 feet 9 inches in length, and $4\frac{1}{2}$ inches in diameter, and to be pierced for 11 pairs of radial arms, 2 feet 6 inches apart, and 2 feet 7 inches in length. These radial arms to be hard wood 1 inch square, to the ends of the pair of which, are to be fitted 11 floats of dimensions 2 feet 6 inches by 1 foot 8 inches. The floats to be made of wood and sheet iron, the wood to be pairs 1 foot 8 inches length, 1 inch square, and grooved to receive the sheet iron. The joints and radial arm and float frames to be connected and tied by $\frac{1}{4}$ inch iron rod on both sides, the floats to be at an angle of 25 degrees from radial line, and secured in position by oblique ties from a joint of radial arm and float frame to the tip of the next float, of $\frac{1}{4}$ inch iron rod, and the tips of the floats to be tied by $\frac{1}{4}$ inch iron rod on the periphery of the water-wheel.

The form and dimensions of the water-wheel herein styled the "Hydraulic Propeller on Mountain Tramway" are given in *Figs.* Nos. 1, 2 and 3 of the drawings annexed to this article.

This Specification of invention has reference in the second place to a form of Tramway consisting of a channel, placed midway between and parallel to a pair of trams or rails, and below the level of rails to a dimension equal to radius of water-wheel, minus radius of running wheel, plus $\frac{1}{18}$ radius of water-wheel: or, according to the dimensions fixed upon for the drawings, the space below the surface of rails or trams to bed of channel $=$ 4 feet 6 inches $- 9'' + 3'' = 4$ feet.

From the foregoing, it is ascertained that the water-wheel with shaft or axle on the ends of which are running wheels one-sixth of the water-

wheel in diameter, the whole rigidly fixed in all parts, constitutes the "Hydraulic Propeller."

And a pair of trams or rails with gauge to fit that of the pair of running wheels on the shaft or axle of the Hydraulic Propeller, with a troughed channel between the rails to receive the floats or fans of the propeller, constitute the "Mountain Tramway."

The mode of working the Mountain Tramway by the Hydraulic Propeller is as follows:—

The Propeller being placed with its running wheels on the trams, and its floats within the troughed channel; water being permitted to flow in sufficient volume within the channel, will cause the water-wheel to revolve, and the revolution will be communicated to the running wheels on the trams in an ascending direction on the incline.

The rate of progress on the ascent will be equal to half the velocity of the stream within the channel, and will therefore decrease with the rate of inclination.

The dimensions of the water-wheel in diameter, breadth and size of floats, will vary with the rate of inclination, and as a water-wheel of dimensions according with any given rate of incline, cannot be worked on an incline of different ratio, it is essential to preserve one rate of inclination for as great a length as possible, and advisable to increase the rate of incline progressively on the ascent.

To make the motive power (obtained as described,) available for the conveyance of goods and passengers, the two running wheels of the propeller are connected longitudinally by a pair of light frames with two or other pairs of running wheels, one pair in front, and one pair behind the propeller, and these other pairs of wheels are connected by axles of square 1½ inch steel bar. Bushes are to be fitted in the ends of the pair of light connecting frames, to receive the axles of the other pairs of wheels, and on the centre of the frames, a half bush with bridged hinge, will receive the axle of the propeller, which is thus made movable, to admit of the propeller being detached and lifted out of the water when descending the incline, or when necessary to stop in ascending.

The propeller may be lifted out of the carriage frame either by a lever or a screw. The half bushes to be provided with friction rollers.

The axles of the propeller and outer pairs of running wheels to be

rounded off, and reduced to an inch in diameter to fit the bushes in the carriage frames.

The carriage will be constructed of iron rod, and wire netting in connection with the frame; the form and dimensions are shown in *Fig.* 4. The weight of the propeller is 180 lbs., and the carriage body with two pairs of running wheels 904 lbs. A passenger carriage load with luggage, with two natives with tools will be 1250 lbs., and the total weight of propeller and loaded passenger carriage lbs. 3334. The weight of propeller and goods carriage will be 1500 lbs., and weight of goods may be 4000 lbs. on the higher inclines.

The greatest load of goods it is proposed to carry including weight of propeller and carriage is two tons. The following table shows the load capacity of propeller on tramway for varying rates of inclination:—

TABLE.

Of Velocities, Horse Power, and Load capacities of "Hydraulic Propeller on Mountain Tramway."

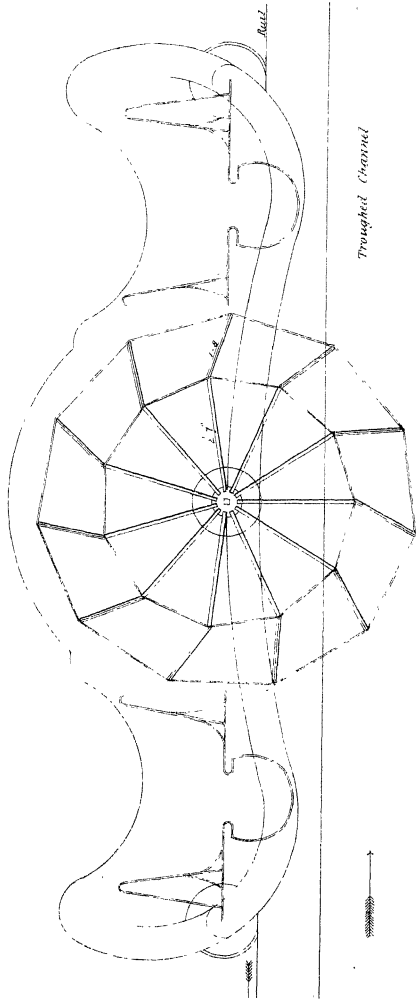
$$\text{H.P.} = {\cdot}0025 \left(90\sqrt{\frac{a}{b} \div s}\right) \left(90\sqrt{\frac{a}{b} \div s} \times {\cdot}56\right) \text{I} \left(\text{V} - v\right) \times x$$

Gradient = s.	Sectional area of tramway channel stream, sq. feet, } = a.	Wetted contour of channel, feet, ... } = b.	Velocity of channel stream, feet per second, ... } $90\sqrt{\frac{a}{b} \div s} = \text{V}$.	Velocity of perimeter of Propeller, feet per second, } $90\sqrt{\frac{a}{b} \div s} \times {\cdot}56 = v$.	Area of immersion of Propeller, float, sq. feet, ... } = I.	Discharge of channel stream, cubic feet per second =	Horse Power = H.P.	Co-eff., resistance of gravitation = x	Load capacity of H.P. on inclines.	Miles per hour.
1 in 20	4·13	5·78	17·00	9·50	3·00	72·21	4·18	·46	2·50	6
40	5·50	6·60	12·80	7·20	4·35	70·12	3·10	·55	2·40	5
60	6·08	7·16	10·90	6·10	5·12	66·27	2·50	·61	2·20	3·90
80	6·82	7·90	9·90	5·50	5·76	65·78	2·25	·65	2·10	3·70
100	7·34	8·00	8·90	5·00	5·92	65·33	1·69	·75	2·00	3·50

PLATE XXXIX

HYDRAULIC PROPELLER ON MOUNTAIN TRAMWAY.

LONGITUDINAL SECTION OF PROPELLER AND CARRIAGE.

Scale 3 feet = 1 inch

The manner of placing and fixing the troughed channel in its proper position within the trams, will vary with the form of general construction of the Mountain Tramway.

For considerable lengths the Tramway may be constructed of masonry on the surface of the ground, with section given in *Fig.* No. 5 without interfering with the waterway.

Where extensive waterway must be provided, or in crossing unavoidable depressions, the design is a simple combination of iron, timber, and wood framing; which is practicable, from the light load it is proposed to run on the Tramway. This form of structure is so light, that it may be borne on timber frames, above the surface of the ground, over those portions of the line where the necessity for expensive masonry works would attend a permanent railway intended to bear ponderous locomotives and heavy trains. The design for the mountain tramway in this case (*Fig.* 6,) is described as follows :—

Iron round bar 1½ inch is formed into lengths of 72 feet stringers, there are two pair of iron bar stringers placed 6 feet apart horizontally and vertically; the vertical pair are connected by wooden posts 6 feet apart longitudinally, these posts being connected again by iron rod diagonal ties, thus the two vertical pair of iron bar stringers, with posts and diagonal ties, form a pair of lattice girders of the lightest possible construction, and these "stringer lattice girders" rest upon timber tressels which may bear the structure 25 feet above the surface of the ground. For greater heights the supports should be of cast-iron or of masonry.

The stringer lattice girders are connected transversely by the cross bearings of the troughed channel, and tied by the framing which supports the troughed channel.

The weight of this structure for 72 feet span will be 7500 lbs. or 3·35 tons. The tenacity of the 2 pairs of stringers, not including that of the rails and bearings, will be equal to 59 tons, and the greatest strain will be 7½ tons. The safe running load will be 10 tons.

The form and dimensions of the mountain tramway on bearing frames are shown in *Fig.* 6.

To meet the contingency of unavoidable crossings of mountain gorges and ravine like vallies, a combination of direct tension and compound Catenary suspension, has been designed for spans up to 500 feet of wire rope. The transverse ties and channel supports are similar to those of

the stringer girder on bearing frames. This design to apply wherever the tramway is more than 75 feet above the surface of the ground. (*Fig.* 7.)

In order to bring the centre of gravity of the moving load low down, and within the framework, the pair of Stringer Girders are placed 6 feet apart, centre to centre, and the trams being placed on the inner edges, the tramway gauge is 5 feet 6 inches, which admits of the load being suspended below the axles, and the bottom of the carriage 6 inches above the troughed channel, which is 1 foot 6 inches by 3 feet 2 inches in breadth.

The sectional area of the stream within the channel on an incline of 1 in 20, is 4 feet. The velocity is 17 feet per second, and the discharge 68· cubic feet per second.

Having thus described this my invention, as aforesaid, I hereby declare that what I claim as of the invention is—*First*, a wheel with floats after the manner of a common water-wheel, with an axle extending to the length equal to the gauge of a tramway, upon which run a pair of wheels affixed to the ends of the water-wheel axle. And a pair of frames connecting the water-wheel axle, with axles of two other pairs of running wheels, thus transmitting the motive power to the tramway carriage.

Secondly, the troughed channel to conduct the stream of water, to act upon the water-wheel, placed parallel to, and midway between the trams or rails as afore described.

And *lastly*, the light form of tramway, in which iron bar, in the form of stringer girders, connecting and binding lattice work of wood and iron rod, the stringer lattice girders supported by bearing frames, over the parts of the tramway line where a large provision of waterway would be requisite, or over unavoidable depressions.

And this invention is styled the "Hydraulic Propeller on Mountain Tramway."

The design for wire rope suspension over mountain gorges and ravine like vallies, being a combination of direct tension and compound catenary is not a new invention.

Thus a carriage of the lightest weight is substituted for the ponderous locomotive, which may be run on the lightest possible form of tramway,

CHANNEL FOR THE HYDRAULIC PROPELLER.—MOUNTAIN TRAMWAY.

TRANSVERSE SECTIONS OF THE SEVERAL FORMS OF CONSTRUCTION.

Scale, 5 feet = 1 inch.

Fig 5
Masonry Structure on surface of Ground

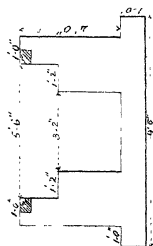



Fig 6
Structure of Wood & Iron on Timber Bearings

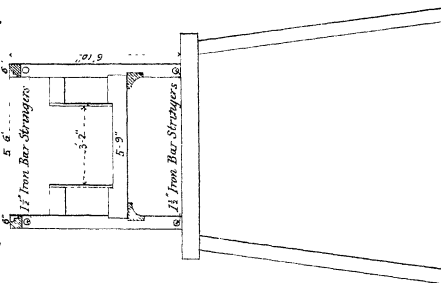
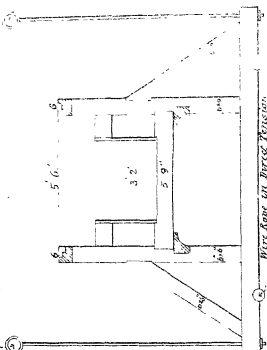



Fig 7
Wire rope in Compound Catenary Suspension

yet fully providing for any requirements that may arise from extended traffic in the hill country.

The vallies of the Kossilla and the Giree have been explored for the "Mountain Tramway," and it is estimated that the three forms of construction will be of length in proportion as follows:—

1st.—Masonry or ground surface 40 per cent.

2nd.—On timber bearing frames 54 ,,

3rd.—Wire rope suspension 6 ,,

To meet objections to so fragile a structure it is observed—

1st.—That the traffic requirements in the hills will be fully met by this tramway with a moving load $1\frac{3}{4}$ tons, including the propeller and car, seeing that a hundred cars may run separately, 100 feet apart, at the same time, worked by the power of the same stream.

2nd.—Massiveness and rigidity of structure, involving enormous expenditure in the formation, bridging and permanent way, absolutely necessary to bear the weight ordinarily passed over railways, are not in any degree requisite for this mountain tramway, and in considering this structure, all ideas connected with permanent Railways must be set aside.

The following investigation of weight, strength and bearing powers, proves that the structure is fully equal to all requirements for stability under the traffic load it is to carry. Extracting from details of specification and drawings, the weight of structure on bearing frames is as follows:—12 feet span.

	lbs.	
Iron bar stringers (4), 72 ft. by 5·9, ...	1,619	
Diagonal Iron braces (36), 1·75 ft. ·875, ...	526	
Cast-iron rails 12-5 lbs. per yard, ...	600	
Fish plates, bolts, spikes, &c., ...	150	
Sheet iron channel, ...	517	
Weight of Iron, ...	3,412	
12 pairs Lattice posts, ...	2,250	
144 feet Rail, bearing 3 ins. by 2 ins, ...	300	
Channel Sheathing and Bearing, ...	1,520	
Weight of Wood, ...	3,970	
Total weight of Structure,	lbs,	16,382
	tons,	4·63
The transverse strength of the four Stringers is	lbs.	
1255 by 4 by ·7854, ...	125,521	
And of the channel, ...	7,280	
Ditto of Rails and bearing, ...	8,750	
Total transverse strength,	lbs,	141,531
	tons,	64

The total weight of structure is little more than one-sixth of its breaking weight.

		tons.
The greatest strain on the pair of stringer lattices is,	...	13·72
The tenacity is $\frac{(4)\ 39537 \times \cdot 7854}{2240}$,	... ...	180·00

The tenacity above strain of the whole structure of the stringer lattices, 43·48

From the foregoing it may be deduced for 72 feet span that the strength of the entire structure is equal to the transverse strain, plus moving load by 4·12.

The safe load is 5 tons, and it is proposed to run $1\frac{1}{2}$ tons, or less than one-third the safe load.

The structure is altered for wire rope suspension by the substitution of the direct tension wire rope for the iron bar stringers.

The tensile strength of Russ. wire of $\frac{1}{20}$ to $\frac{1}{30}$ is 6 to 9 times per square inch that of a square inch of bar iron; the cost is much greater, but the greater dependence on the wire renders it advisable to make the rope entirely of strands of $\frac{1}{16}$ Russ. wire. The following has been deduced for

216 FEET SPAN.

Weight of structure suspended, 12 tons.

The tensile strength of structure without the catenary suspension, is	
Direct tension, wire ropes 3375 square inches $\times$ 59 5	= 200
In the cast-iron rails continuity would be destroyed, but as four fish-bolts of $\frac{3}{4}$ would give a tenacity equal to half the tensile strength of rails and bearings, it should be substituted, ...	18
Total tensile strength of structure, ...	218
Strain at centre equals, ...	58

The difference of tensile strength and strain is so great, that the latter need not be taken into account in providing for suspension.

Wire rope of 323 strands of $\frac{1}{16}$ Russ. wire would be $4\frac{1}{3}$ inches in diameter, containing sectional area of iron of 1·69 inch, and a pair of ropes = 3·375 inches, would amply provide against weight, strain of structure, and high wind.

The safe load sanctioned by the Lords Commissioners of the Admirality on wire cables,—that is, ship's strain at anchor under a high wind, is half the breaking weight: and a wire rope of the dimensions given would

sustain 90 tons, and a pair 180 tons, and the greatest strain that could be brought on the structure suspended over 216 feet span would be 60 tons, or one-third the breaking weight, which is—

By Admiralty trials,	...	...	...	...	180 tons.
„ Hodgkinson's ...	...	...	...	...	200 „

The latter being received as most trustworthy by the profession generally.

The propeller of 9 feet diameter can be used only where there is sufficient flow of water, either from a perennial stream of full, or by storing a stream of insufficient, capacity. Where water has to be accumulated by storage, the propeller could be run, say once in seven days, when the water flow should be permitted for a certain time, say six hours. Suppose such a tramway 20 miles in length, the flow of water in the tramway channel or six hours would work up 90 tons weight in 100 carriages, each carriage provided with its propeller and following on in succession.

For velocity and discharge in the tramway channel we have as follows:—

A = Sectional area of stream, $3{\cdot}18 \times 1{\cdot}30$ = 4·134 sq. feet.

WC = Wetted contour, ... 5·78 feet.

r = Hydraulic mean depth $\frac{A}{WC}$, ... 0·71 „

s = Gradient, ... 20

$V = 90\sqrt{\frac{r}{s}}$ = velocity, ... 13·5 ft. per. sec.

$v = 90\sqrt{\frac{r}{s}} \times {\cdot}56$ = velocity of perimeter of propeller, 7·6 „

I = Area of immersion of propeller float, $2{\cdot}5 \times 1{\cdot}8$, ... 2·95 sq. feet.

H = Horse-power $= I\left(90\sqrt{\frac{r}{s}}\,{\cdot}56\right)^2 (V - v)$ ... 4·20 „

And a 4·20 horse-power propeller, ascending an incline of 1 in 20 at the rate of 6 miles an hour, would take a load of 2½ tons, as is shown in the table. *See* Specification of Invention.

The tramway channel discharge on such an incline would be 72·21 cubic feet per second, so that a perennial stream of less capacity would have to be stored. Such a stream descending to the Kosi was measured as an experiment. In the driest season this spring stream gave 8 cubic feet per second, or 292,800 cubic feet in six hours. This stream, if stored in

eight reservoirs 120 × 12 × 12 feet each, would provide sufficient water to work the tramway for six hours once a week.

The foregoing is to show that in the event of partial failure of water-supply, or in localities where it is scarce, the power can be accumulated in reservoirs at the summit, and along the line, for a tramway with propeller 9 feet in diameter, and of corresponding dimensions.

The cost of reservoirs would be Rs. 1,000 per mile, in addition to cost of tramway construction.

It should not be omitted that this mountain tramway may be constructed to any dimensions, from a toy model to the largest upon which the necessary discharge would be manageable.

A model tramway one-sixth of the proposed dimensions would give by computation—velocity $2\frac{1}{4}$ feet per second, velocity of perimeter $1\frac{1}{4}$ feet per second, horse-power ·068, and load capacity 80 lbs. Under experiment, a load of 135 lbs. ascended an incline 1 in 20, 25 feet in length, in 9 seconds. This model tramway, with its small propeller and discharge in channel of only half a cubic foot of water per second, would take a maund in each carriage, and there might be a hundred carriages at once on the tramway, so that it would convey a traffic of 100 maunds per diem.

And, if the subject of the cost were reduced to one of secondary consideration, the largest streams could be provided with a channeled tramway and propeller of the largest dimensions, within the limits of control of water power. The principle of this new invention may be carried to the extent of channel discharge of 3,000 cubic feet per second, giving 50 horse-power on an incline of 1 in 80, with 7 miles an hour on the ascent. A work of such magnitude would, however, be enormous in cost.

At this period, any scheme for a tramway penetrating the hill country, must have for its object the accommodation of the military sanataria, but the mountain tramway with hydraulic propeller is designed especially for the ascent of vallies and ravines in which there are perennial streams of sufficient capacity. In the larger vallies, an altitude may be attained at distances beyond existing traffic, but the developement of agricultural and mineral resources, and the consequent increase of population may lead in time to the spread of the tramway system over the plateaus distant from mountain rivers, and one or other of the several methods of application of the water-power, described at pages 474,475 may be adopted to

reach localities where water is scarce, as would generally be the case at elevations 6000 to 7500 above the sea, distant from the rivers and their tributaries: but there are generally small rills which, with rain-fall, might be stored to work the tramway at timely intervals, of three to six days. The military and other hill settlements are already in the list of localities for which provision should be made, and it is in consideration of these that the several methods of extending the utilization of the water power of mountain streams has been suggested. Raneekhet for instance, 12 miles distant from the Kossila valley could be accommodated by storing water to work the propeller on the channeled tramway. The expenditure would be 756,000 cubic feet in three hours, the time requisite to pass up the tramway from the Kossila valley to Raneekhet; over a portion of the distance, probably a sufficient supply may be had from the stream running to Bhojan. A rill of one cubic foot per second, would keep up the supply for working the tramway every fifth day, and so would the rain-fall of 2 inches over a square mile, allowing for absorption and evaporation.

The vallies of the Giree and the Kossilla may be taken as representing the nature of the ground to be passed over by any tramway ascent of mountain river openings, and the cost of construction may be approximately estimated for any proposed line.

Taking the proportionate length of the different forms as given on page 481, the mountain traimway 50 miles in length, would cost for

	RS.
The first form—masonry on surface of ground, 20 miles, ...	2,67,280
The second ditto, on timber bearings, 27 miles, ...	5,23,515
The third ditto, wire rope suspension, ...	1,75,086
Total cost of 50 miles, ...	9,65,881
Mean cost per mile, ...	19,320

A tramway car with propeller complete will cost Rs. 240, and the rolling stock of 80 to 109 cars, with stations and other requirements should not exceed Rs. 34,000, bringing the outlay on 50 miles up to Rs. 1,000,000.

An important question arises, as to the mode of working the down traffic on the mountain tramway. The specification of invention has no provision for Brake power, beyond that obtained by raising and depressing, or partially immersing the propeller blades ; at the time of filling the specification this question was deferred for further study. This use of the propeller on the descent as a brake, is objectionable on account of the strain that would result thereon, and it is necessary to have recourse to

some other mode of applying retarding force, avoiding undue strain on the tramway structure as well as on the car; the results of the study of this question are given as follows :—

Friction Roller Brake.—The gradients of a mountain tramway are necessarily steep, and it is necessary to have a brake power, other than that obtained by partially lowering the propeller; moreover in the descent of an incline, it may be advisable, to meet traffic requirements, to load up to tramway safe point, when the propeller may be removed, and a pair of running wheels put in its place. In this case separate brake power would be requisite, which is provided by a pair of friction rollers, made to press against the inner side of the troughed channel by a cross lever acted upon by a screw in precisely the same manner as the ordinary Railway brake.

In addition to this friction roller brake behind the carriage, a similar apparatus acted upon by a governor, when the arms are raised by centrifugal force at high speed; the motion of the running wheels is given to the governor shaft by a pair of mitre cogs. At a speed of 20 miles an hour, the governor shaft would have 6·4 revolutions per second, and the governor would be brought to act upon a cord, which is attached to a loose toothed collar, and drawing it in contact with a fixed toothed collar locking them together on the axle, and winding upon the collar, to which it is attached, a band or flat chain which acting upon a cross lever will draw the front friction roller brake into action.

The difference between the rear and front brakes is, that the former would depend upon the presence of mind and activity of the guard, while the latter is brought into action by undue velocity of the moving car descending the tramway incline.

The study of this simple and efficacious method of the application of an arresting force leads to a diversion from mountain tramways to Railways in general.

The present form of Railways renders necessary an enormous weight of engine and carriages; resulting in wasting "wear and tear." There appears no reason why the troughed channel could not be laid between the tracks of a Railway for the especial working of horizontal friction rollers, in the manner described for the mountain tramway car when descending a steep gradient; the rear friction roller brake to be applied by the guard, and that in front automatically applied at undue high speed.

If the channel were lipped, the danger of leaving the track at high speed, (which is provided against on Railways as constructed, by enormously heavy locomotives, and carriages with the concave tired wheel, or flanged wheel rendering necessary the expensive rail and permanent way,) would be removed.

Instead of expending so much on rails and sleepers—the channel between the tracks, would be much less than that of the lightest rails. The channel might be formed in tolerably level country and in cuttings, of two walls with flat iron bar 3 inches by $\frac{1}{2}$ inch let into the masonry and tied through at 20 feet intervals.

The idea of applying the channel between tracks of Railways in general, was communicated to the present writer by Captain Thomason, R.E., in a conversation in which the friction roller brake on the mountain tramway was being explained. Captain Thomason suggested the channel with powerful framing below the carriage, holding two pairs of friction rollers to act alternately in the sides of the channel—to counteract lateral motion of the moving train ; this alone would permit of the reduction of weight of rolling stock to a fifth, the abolishment of the heavy concave tired wheel, and the heavy and expensive rail ; but the employment of the friction rollers as brake power would do away with the necessity for heavy running wheels and correspondingly massive form of track, which would be necessary for the application of the ordinary brake to running wheels. The whole effect of the train in motion, from tangetic force on curves, or from tendency to lateral motion from whatever cause, would be confined to the inner sides of the channel, and the running wheels being left free, simply to carry the load in motion, may be of the lightest form, and of much enlarged diameter.

This paper being intended to describe the mountain tramway only, no calculation as to extent of reduction of weight of Engines, &c., on Railways have been made, but it may be supposed that the reduction would be so great as to permit the use of material much lighter and cheaper than iron, and a steam carriage road as described below, possibly may meet all demands, and be as safe as the heavy railway.

The steam carriage road to be 4 feet, formed of two sections of masonry 4 feet apart, and coped with ashlar.

The masonry with 20,000 cubic feet of ashlar track and coping, and 80,000 cubic feet rubble masonry or brick work—would cost say Rs.

36,000. The roller plate, if of flat iron bar, 2,000. The track, monolithic of Hurdwar cement, say 3,600. Total about 40,000 per mile without bridging, and this item of cost might be much reduced by combination of suspension and girder, admissible by so great reduction of moving load.

The automaton brake brought into action by a governor drawing the loose, and fixed toothed collars into contact, as described above, and thereby bringing the momentum force to act upon the cross lever bearing upon the friction rollers and pressing them against the side of the channel, is a new application, in connection with the specification of invention, but the power for brakes on running wheels taken from their revolving axles was invented by Mr. J. Clarke, C.E., some years ago, who obtains his power by bringing friction rollers in contact with the perimeters of the carriage wheels while in motion. Clarke's brake is in use on the North London Railway; it is too powerful and sudden in action on a Railway where such frequent stoppages are requisite, and is suited to long lines, and for emergencies.

The suggested new steam carriage road with friction roller brakes acting on the channel, mid tracks, would be admirably suited for long Indian lines. The brake should have two modes of application action, the ordinary screw and lever, and the automatic as described.

Water power in the plains.—The question of the water-power of mountain streams naturally leads to a consideration of the Rivers and Canals over so large an area of the Punjab. Then the rivers rising in Central India, and the tributaries of the Jumna and the Ganges. The rivers running out from Sirmoor, Gurwhal and Kumaon, require attention first, as being in connection with suggested mountain tramway routes.

The water flow of the rivers of Punjab and Rohilcund would be employed with great advantage in lieu of steam, either by rope traction or by working pneumatic apparatus, such as the tube and piston valve of the atmospheric railway principle—on tramways conecting the Oude and Rohilcund and the Delhi and Rohilcund Railways. As to the form of road best suited to the atmospheric table; the track should be of Hurdwar cement, 3 by 3 inches laid in grooves of masonry, which should have a fender wall, two feet above level of the track to receive the touch of horizontal friction rollers, and prevent swerve or oscillation, which would interfere with the precision of the action of piston valve in tube.

A light tramway laid above the surface of the ground, and worked

by atmospheric pressure, by the water power, could be laid through the Dehra Dhoon with facility and ecconomy. At Dehra there is sufficient water power to work east and west between the Jumna and the Ganges. At Bogpoor there issues a masonry canal with sufficient water to work a branch tramway northwards, from a point 8 miles distant from Hurdwar.

The subject of light tramways worked by water power on rope traction, or by exhausting a tube on the "Atmospheric Railway" principle, as affording an inexpensive means of communication through the tract lying between the Railways and the foot of the hills, in conjunction with the Mountain Tramway, is worth attention.

In the Ganges Canal Falls an enormous water passes unemployed. Take the first fall from the Canal Head we have,

Discharge = D = 4000 cubic feet per second.
Fall = F = 8·5 feet "
Whole power of fall = H.P. 2018

The falls are divided into 10 bays, so that in one bay the discharge is 24,000 cubic feet per minute,

$$\text{H.P.} = \frac{24000 \times 523 \times 85 \times 5}{33000} = 202$$

To utilize a part of this water power for the working of a light tramway by rope traction, or by any of the methods described; a breast-wheel 22 feet in diameter, width 6 feet, with depth of bucket 2·5 feet, would afford H.P. 73, and three wheels between Roorkee and Hurdwar would work a heavy traffic on a Railway laid on the banks of the canal. A light road, with constant movement of cars throughout the day, instead of a costly railway is suggested.

Canals having a regulated flow offer a means of employing water power in this country which should not be overlooked. Even with a very slight fall, large wheels, with additional mechanical motions, could be made to draw 10 tons on a light tramway, even where there are no overfalls. This especial question of the utilization of the water power of canals as a tractive force is worthy of consideration in the "vexed question" of "Irrigation and Navigation."

These suggestions are offered for consideration at the time of commencement of several long lines of Indian State Railways, whether, as to the substitution of the cheap steam carriage track for the heavy rails, referred to in page 487.

Or, as to the utilization of the water power of rivers where it may be available for the working of railways, either of rope traction, or atmospheric propulsion.

They are however especially recommended to the attention of Government and of those interested in the developement of the resources of the districts on the outer slopes of the Himalayas as pointing to a certain, and economical means of providing for traffic communications at a cost commensurate with their probable requirements.

NYNEE TAL, 14*th February*, 1872.

W. S.

No. XLVI.

KUNKUR AND MORTAR ANALYSIS.

By Murray Thomson, M.D., F.R.S.E., *Professor of Experimental Science at the Thomason Civil Engineering College, Roorkee, and Chemical Examiner to the Government, N. W. Provinces.*

In a recent number of *Allen's Indian Mail*, it was stated that Captain Ross, R.A., in a lecture he delivered at the United Service Institution, had said, that Kunkur, so much used in India for the making of mortar, contained no lime. Some time ago I was called upon to state whether this was in accordance with my experience, and I had no hesitation in replying that it was not. I have analysed several samples of kunkur, and have never met with one which contained less than 28 per cent. of carbonate of lime, and in by far the greater number of specimens the proportion was a little over 50 per cent. Captain Ross's statement perhaps was founded on the analysis of a substance, which may have resembled kunkur, but even that is not likely, as the appearance of kunkur is very characteristic. A table containing six analyses made by myself, two by Captain Badgley, B.S.C., when he was a student at the Thomason College, and one by J. Prinsep, Esq., will be found on page 496.

As the thorough analysis of a kunkur or limestone is an operation which few Engineers can perform for themselves: the following process, which, will give a rough approximation, has been suggested. Pound a sample in a mortar, pass it through a fine sieve: put 150 grains in a tumbler, and pour gradually on it diluted hydrochloric acid, stirring it with a bit of wood: add the acid until effervescence ceases, then, filter it through blotting paper, and wash by pouring fully a quart of water through the filter; that which remains is clay or sand or both: it should be carefully

dried, collected and weighed; the difference between this weight and the 150 grains represents *Carbonate of lime.* This remainder should now be repeatedly washed by decantation, so as to get rid of the lighter particles of *clay*, until *sand* alone is left, which should be dried and weighed. If the 150 grains are found to contain

Carbonate of Lime, ...	112	grains.
Clay, ...	9	"
Sand, ...	29	"

the stone will furnish a fair lime for general purposes.

Another simple plan which may be employed is to weigh a piece of the stone after it has been thoroughly dried: then heat it to redness in an open fire (say for four hours) to expel the carbonic acid: allow the stone to cool, and again weigh it, the loss of weight will show the amount of *Carbonic Acid* from which can be calculated the amount of *Lime*: as in every 100 parts of Carbonate of Lime, are 56 parts of Lime, and 44 parts of Carbonic Acid.

If however the Engineer's opportunities and appliances allow of a *thorough* analysis, this should always be made.

I would recommend the following process, which I have drawn up so that it may be used for a Mortar as well as a Limestone.

1. *Selection of the sample.* Care should be taken to get a fair average sample. In the case of a mortar a handful from various parts of the heap should be taken, and these thoroughly mixed, about two ounces of this should then be put in a well closed bottle. In the case of a limetone or kunkur, a piece should be broken off from various parts of the mass, or if it exist in several pieces, then parts of each should be taken.

2. *Preparation of the sample for Analysis.* The sample should now be reduced to powder, first in an iron, and then in an agate mortar. The powder should be so fine, that no grit whatever can be perceived when a little of it is rubbed between the fingers. From 5 to 6 grammes of the sample should be thus pulverised, and kept in a stoppered bottle labelled with a label corresponding to that of the sample.

3. *Estimation of the water.* It will be sufficient to dry about one and a half grammes, at 100.C until it ceases to lose weight, and the loss entered in the analysis as water; for a more accurate process for estimating water in a limestone, as well as for fuller details on the analytical process generally reference is made to Quantitative Analysis by Fresenius (3rd Edition, page 553.)

4. *Estimation of the siliceous residue.* About two grammes* of the sample are put in a beaker glass, and covered with half an inch of distilled water, the beaker is now inclined to an angle of 60°, and some pure hydrochloric acid is added. The inclination of the beaker is to prevent loss by spirting during the effervescence. When the effervescence has ceased, a little more acid is added, and the whole is then slowly evaporated to dryness. The last part of the evaporation must be done in an air bath. As soon as the mixture is quite dry, about half an ounce more of distilled water must be added along with a few drops of hydrochloric acid, the mixture made warm and filtered, what insoluble matter remains on the filter is now thoroughly washed with hot distilled water, the washings being allowed to fall into the first filtrate. The residue on the filter should be washed until a drop of the washings leaves no residue when evaporated on a bit of platinum foil. The insoluble residue on filter is treated as para. 9 directs.

5. *Estimation of the Oxide of Iron, Alumina, &c.* The acid filtrate and washings are now heated to boiling, and strong liquor ammonia cautiously added, until after the last addition the mixture smells distinctly of ammonia. A brownish red precipitate will have fallen by this treatment, this precipitate is now to be collected on a filter, and rapidly washed with boiling distilled water. The precipitate or the filter is to be treated as para. 11 directs.

6. *Estimation of the Lime and Magnesia.* The filtrate and washings from the last operation are now well mixed and divided into two equal parts, which may be called A and B. In A the lime, and in B the magnesia is estimated.

7. Portion A. is now heated to boiling, and while in ebullition 20 cubic centimetres of a standard solution of oxalic acid are added† care should be taken that the mixture is still alkaline after the addition of the oxalic acid if necessary, a few drops more ammonia should be added. The precipitate of lime oxalate which has been produced is now separated by filtration, and the precipitate is washed by boiling water 3 or 4 times. The filtrate is now warmed to 60° C., 2 C.C.‡ of oil of

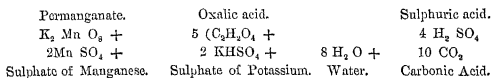
* All weights taken must be made accurately with a balance which will turn easily with a milligramme, when the scales are loaded with 50 grammes each.

† This standard solution of oxalic acid is made by dissolving 31·5 grammes of ordinary crystalised oxalic acid in a litre of distilled water. A label should be affixed to this solution, to the effect that each cubic cent. contains 0315 of a gramme of oxalic acid, and corresponds to ·014 of Lime.

‡ C. C. Means cubic centimetre.

vitriol are added, and a standard solution of permanganate of potassium gradually dropped in, until its color remains permanent.

The process just described, is a very rapid and very correct one, for the estimation of lime, and where many limestones or mortars have to be analysed, it is well worth while to prepare and keep ready a small stock of the two standard solutions required. The preparation of the permanganate solution is described below.* The process may be explained thus, enough of the oxalic acid solution is added to precipitate, all the lime, and leave an excess of itself in the filtrate. The amount of this excess of oxalic acid is then determined by the standard permanganate solution, which decomposes the oxalic acid in the presence of sulphuric acid, and at a certain temperature into carbonic acid, thus :—

Permanganate.	Oxalic acid.		Sulphuric acid.
$K_2 Mn O_8$ +	$5 (C_2H_2O_4$ +		$4 H_2 SO_4$
$2Mn SO_4$ +	$2 KHSO_4$ +	$8 H_2 O$ +	$10 CO_2$
Sulphate of Manganese.	Sulphate of Potassium.	Water.	Carbonic Acid.

While this action is going on, the fine purple color of the permanganate disappears, but as soon as it is completed, the color of the permanganate remains. The amount of solution of permanganate used to produce this permanent color is then read off, and every 10 C.C. of it correspond to 1 C.C. of oxalic acid solution. All that is necessary to complete the estimation of the lime is from the permanganate used to calculate the oxalic acid in the filtrate: this oxalic acid is over and above what was required to precipitate the lime, and if now it be deducted from the 20 C.C. used, the remainder has to be calculated out as lime, at the rate of 1 C.C. of oxalic acid solution, corresponding to ·0112 of a gramme of lime. The result should be multiplied by 2, as only half the filtrate was used.

The only trouble about this process is the preliminary one of preparing the standard solution of permanganate and oxalic acid, but once these are prepared the estimation of the lime is easy and rapid, and that cannot be said of any other method of estimating lime.

8. Portion B is now to be employed for the estimation of the magnesia for that purpose, it is heated to boiling, and oxalate of ammonium is added in slight excess. The mixture is then allowed to stand 12 hours

* 10 grammes of crystals of permanganate should be dissolved in a litre of distilled water This solution should then be titrated by the standard solution of oxalic acid, so that 10 C.C. of the Permanganate will equal 1 C.C. of the acid.

at the end of this time the precipitate of oxalate of calcium will have completely subsided. Now the clear fluid is separated by decantation, and the precipitate collected on a filter, and washed with cold water. The washings and decanted fluid are now mixed, and ammonia added until the solution smells of it, and then solution of phosphate of sodium, the whole is then well stirred. If the stirring is kept up for 15 or 20 minutes, the whole of the magnesia will be thrown down as magnesium and ammonium phosphate, which may be at once collected on a filter and washed with cold water, having about $\frac{1}{10}$ of solution of ammonia added.

9. The insoluble residue obtained by process in para. 4, is now, having been dried, incinerated along with the filter and weighed, a certain amount is deducted for filter ash, this amount is ascertained by incenerating 10 filters, and dividing the ash obtained by 10. The weight of the residue is now calculated as a percentage result, and entered in the analysis as residue insoluble in hydrochloric acid or simply siliceous residue. It contains any sand, clay, and organic matter which may be in the sample.

10. In the case of a hydraulic limestone, the clay in this insoluble residue ought to be estimated: for this purpose, it should be thrown little by little into a boiling solution of carbonate of soda (best boiled in a silver vessel). The pure silica or sand will be thus dissolved, and the clay left insoluble, it is only needful to ascertain the weight of the latter after thorough washing, drying and incineration.

11. The precipitate of oxide of iron and alumina obtained in para 5, is now incinerated and weighed, and after deduction for filter ash calculated as a percentage, and entered in the analysis as oxide of iron, and alumina dissolved by hydrochloric acid.

12. The precipitate of magnesia ammonium phosphate obtained by para. 8, is also dried, incinerated and weighed, and the amount multiplied by 2, as only half the filtrate was used, (it should be well dried before incineration,) filter ash being deducted. Every 222 parts of the substance weighed contains 80 of magnesia, its composition being the magnesium pyrophosphate $Mg_2\ P_2\ O_7$.

13. *Estimation of Carbonic acid.* In the case of a limestone, it is not needful to estimate the carbonic acid, as all the lime, and all the magnesia obtained in the analysis may be calculated as carbonates and entered in the analysis as such. Every 56 of lime, and every 40 of magnesia require each 44 of carbonic acid. In the case of a mortar, the carbonic acid

must be determined as part of the lime exists as hydrate and part as carbonate. About 3 grammes of the finely pounded mortar are put in a small flask fitted with a chloride of calcium tube, and a very small test tube: in the latter is put some strong hydrochloric acid. The mortar at bottom of flask is covered with distilled water, the small test tube full of acid is lowered in by means of a piece of fine platinum wire, so as to remain upright, and allow no part of its contents to be spilled. The chloride of calcium tube fitted to a cork with a small draught tube, is then adjusted to the mouth of the flask, and the whole is weighed. Then the flask is inclined so as to spill the hydrochloric acid among the water and mortar, (the acid should only be spilled over gradually,) a brisk effervescence ensues from the escape of the carbonic acid when all the acid has been spilled over, and effervescence has quite ceased, a gentle draught of air is drawn through the apparatus by the mouth, the apparatus being now weighed, it will weigh less; the loss shows the amount of carbonic acid.

Analyses of Kunkurs.

	1	2	3	4	5	6	7	8	9
	Saharunpore No. 1.	Ditto No. 2.	Ditto. No. 3.	Allahabad.	Delhi No. 1.	Ditto. No. 2.	Ghazeepoor.	Allyghur.	Ditto, No. 3.
Lime, ...	57·18	79·33	78 54	52·80	53·49	28·97	40 0	15·5	37·0
Carbonic acid, ...							32·0	12·8	30·3
Alumina, ...	10·32	6·73	8·42	3·64	3·00	4·09	11·0	38·4	20·8
Oxide of iron, ...									
Magnesia, ...	trace.	trace.	trace.	none.	1·57	·94	·4	2·8	5·4
Siliceous Residue, ...	32·50	13·94	13·04	42·39	41·41	63·63	15·2	30·5	7·1
Water, loss organic matter, &c.,	not determined.			·60	·67	2·32	1·4	...	...
	100·00	100·00	100·00	99 43	100·14	99 95	100·0	100·0	100·0

Nos. 1, 2 and 3, were sent by Captain Moncrieff, R.E., when he was in charge of the Eastern Jumna Canal.

Nos. 4 and 5, were sent by the late Colonel Anderson, R.E., in connection with the case of the Allahabad Barracks.

No. 6 was sent by Capt. Helsham Jones, R.E., it was being used for the works at Okla, near Delhi.

No. 7 by J. Prinsep, Esq.

Nos. 8 and 9, by Capt. Badgley.

No. XLVII.

ON GRAVATT'S "METHOD" OF ADJUSTING THE "LINE OF COLLIMATION" IN ALTITUDE.

By Lieut. Allan Cunningham, R.E., *Hony. Fellow of King's College, London, and Offg. Professor of Mathematics, Thomason C. E. College, Roorkee, N. W. P.*

Preface.—It is due to the readers of Paper XXI., of these Professional Papers "On the Line of Collimation," to explain that its main object was to define the "line of collimation," and the relative positions of the point chosen for observation, and the intersection of the hairs of a theodolite or middle of the horizontal hair of a level, also to point out that the reasoning at page 84 of Rankine's Manual of Civil Engineering Edition of 1870, (by which it is attempted to show that the adjustment of the " line of collimation " in the Dumpy Level is unnecessary,) is incorrect. The main assertion of Professor Rankine's para. quoted is however *correct*, although the proof given is incorrect: the *implied conclusion* in that paper of the possibility and necessity of Gravatt's Method of Adjustment is *incorrect*: this does not affect the general substance of the paper; the conclusions therein as to "line of collimation," and relative positions of point observed and middle of horizontal hair of a level are (in the author's opinion) correct, and will be used throughout this paper.

In this paper it will be shown that " Gravatt's Method " of adjustment in altitude of the "line of collimation" of a level is a *practical failure*; viz., that it simply *fails* (within the limits of practice), even *to discover any error* in that line. As this so called Method of Adjustment has been *for many years* supposed to be *the most perfect method* available, it is a little startling to find out that it is practically useless.

Most equations employed in Geometrical Optics are only approximations: it may therefore be expected of an author objecting to a method of such repute to show that the approximations he uses are sufficiently accurate.*

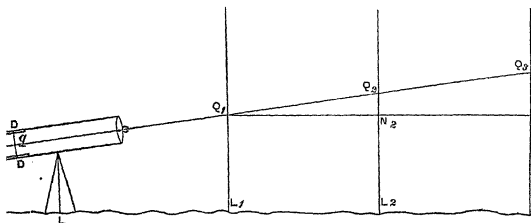
* The *first* approximation to the curve locus hereafter discussed came to the author's notice in a Paper communicated to the Editor of these Papers by D. M'Mordie, Esq., B.E., Q.U. Ireland. The critical discussion of its *sufficiency*, and the experiments are due to the author.

It will be advisable first to explain "Gravatt's method" of adjustment in detail, then to investigate theoretically the possibility of its application within practical limits; lastly, very careful experiments made by the author expressly to test his conclusions will be adduced.

"Gravatt's Method" of adjustment in altitude of the Line of Collimation.

This method in thus performed:—

Three levelling staves $Q_1Q_2Q_3$ are ranged in a straight line Q_1Q_3, and held as upright as possible: the distance Q_1Q_3 must be within the range of good definition of the telescope to be used, (see *Fig.* 1.)

Fig. 1.

The differences of level of the feet $L_1L_2L_3$ of the staves are found as accurately as possible; it is admitted that this can be accurately done with a level, even though not in adjustment, by simply placing the level *midway between* staves Q_1Q_2, and also *midway between* Q_2Q_3, and bringing the bubble to the centre of its run on each occasion of making a reading.

The level, which it is wished to adjust, is then set up on the line $Q_1Q_2Q_3$ as at L far enough from Q_1 to admit of clearly reading that staff. The telescope is directed in the plane of the staves $Q_1Q_2Q_3$, and the bubble brought to some definite position, which can be easily recognised (it is not necessary that it should be in the centre of its run). The three staves $Q_1Q_2Q_3$ are now read in succession; it is essential that the telescope remain quite steady throughout this period; as the staves are in the same vertical plane as the telescope, there is no necessity to touch the telescope except to focus it; any departure of the bubble from its original position must be corrected by the foot screws.

Let $Q_1Q_2Q_3$ be the points viewed and read on the three staves in succession.

Now, applying the differences of level of the feet L_1, L_2, L_3 of the staves already found with their proper algebraic signs to the height L_1Q_1 (= the reading on the first staff), the heights L_2N_2, L_3N_3 at which a level line $Q_1N_2N_3$, through Q_1 cuts the staves Q_2Q_3 can be ascertained.

Taking the differences of the heights of the level line, and of the heights of Q_2, Q_3 above L_2, L_3 respectively, the differences of level of the points $Q_1Q_2Q_3$ can be obtained, thus

$$Q_2N_2 = Q_2L_2 \sim N_2L_2, \text{ and } Q_3N_3 = Q_3L \sim N_3L_3.$$

Now if $Q_1Q_2Q_3$ lie *on any straight line whatever*, the following proportion would evidently obtain $Q_2N_2 : Q_3N_3 :: Q_1N_2 : Q_1N_3$.

Also, if there be no error in the line of collimation, *i.e*, if the middle of the horizontal hair q, *Fig.* 1, traverse the object glass axis qC, it is easily seen (*see* Paper XXI.,) that the "line of collimation" qC always coincides with the object-glass axis, and that therefore, the points $Q_1Q_2Q_3$ (which necessarily lie on the "line of collimation" qC) must lie *on that straight line*, and on trying "Gravatt's method" the proportion $Q_2N_2 : Q_3N_3 :: Q_1N_2 : Q_1N_3$ will of course be found to hold.

But, if there be an error in altitude in the "line of collimation," *i.e.*, if the middle of the horizontal hair be in the position q, see *Fig.* 2, (not on the object-glass axis Co) its middle point will traverse the line $q_1q_2q_3$ parallel to the object-glass axis in the act of focussing for obtaining distinct vision of the staves Q_1, Q_2, Q_3 which are *at different distances* from the level. (*See* Paper XXI).

The "line of collimation" qCQ (Paper XXI.), will no longer be a fixed line, but will have the three positions q_1CQ_1, q_2CQ_2, q_3CQ_3 on viewing the three staves $Q_1Q_2Q_3$, so that the three points $Q_1Q_2Q_3$ will not range on the object-glass axis oC, and it *might be supposed* that the ratio $Q_2N_2 : Q_3N_3 :: Q_1N_2 : Q_1N_3$ would no longer hold.

It *has been actually supposed hitherto* that unless the points viewed $Q_1Q_2Q_3$ lay *actually on the object-glass axis* oC produced, this proportion would not hold, and that consequently if on actual trial, the proportion were found to hold good, it *was supposed* to be a proof that the "line of collimation" was correct, and further, that if on actual trial, it were found that this proportion did not hold, it *was supposed* that the difference of the actual length Q_3N_3 from that required by the proportion, viz.,

$Q_2N_2 . \frac{Q_1N_3}{Q_1N_2}$ would be *a measure of the error in altitude* of the horizontal hair.

Let it then be understood that it is this difference of length, viz., $Q_3N_3 \sim Q_2N_2 . \frac{Q_1N_3}{Q_1N_2}$ that is to say the amount of departure of one of the points Q_3 from the straight line Q_1Q_2 joining the other two, which "Gravatt's Method" proposes to find (by observation), and to consider a measure of the error in altitude of the horizontal hair.

Investigation of the Curve which is the locus of Q.

The form of the curve on which all the points viewed, (*i.e.*, covered by the middle of the horizontal cross-hair) lie, will now be investigated, and it will be shown that it is so flat a curve, that *the departure* of any point on it from a certain straight line (required to be measured by Gravatt's Method) is so small *within the limits practically obtainable*, that it falls within the limit of the errors of observation, *i.e.*, *cannot be measured.*

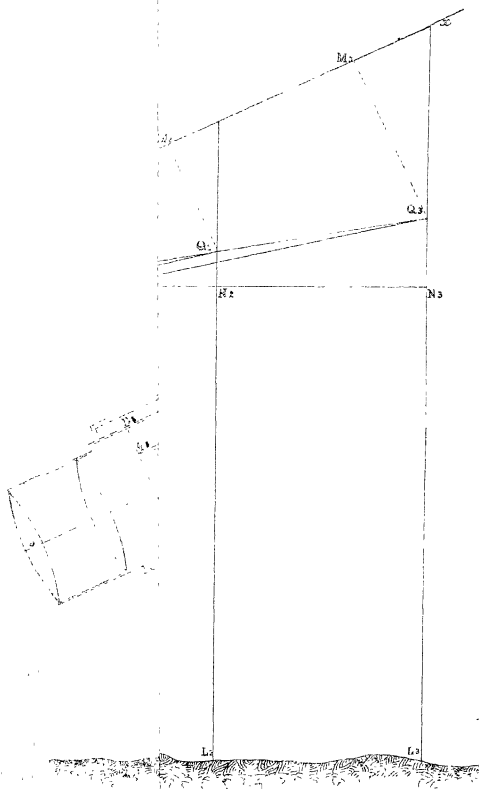
The references are to Parkinson's "Treatise on Optics," 2nd Ed. of 1866, and to Paper XXI., of the "Professional Papers on Indian Engineering," (Second Series.) It will be assumed as follows :—

(1). In spirit levels, the focussing screw moves either the object glass only, or else the diaphragm and eye-piece together: the instrument should be so constructed (by the maker), that (see *Fig.* 2), in the former case, the object-glass "centre" C, (Parkinson, Art. 109,) moves along its axis oC, and in the latter case, the middle of the horizontal hair q should move either along that axis oC, or on a straight line $q_1\ q_2\ q_3$ parallel to it.

(2). The "line of collimation" (*see* Paper XXI.,) is the line qC joining the middle of the horizontal hair q to the "centre" C of the object glass, and is aligned with *the point* Q, chosen for observation, (see *Figs.* 1 and 2.)

(3). The centre of "the circle of least confusion" (Parkinson, Art. 64,) q corresponding to the *point* viewed Q is *the* image of that point (Art. 65.)

N.B. It might be supposed that the achromatic object glass being (in common parlance,) corrected for spherical aberration, there would be no "circles of confusion," (these being due to spherical aberration), but the glass is in fact corrected for spherical aberration *only for parallel rays directly incident*, (Art. 223). Now as the use of "Gravatt's Method" neces-

llimation.

L_1, Q_2L_2, Q_3L_3.

; $CM=x$, $QM=y$, $CM=r$,

sitates reading a staff as close to the object-glass as distinct vision will admit, the incident rays are not parallel, but *divergent*, and are also not directly incident, but *oblique* whenever the horizontal hair is out of its proper position (the very case in hand), so that "circles of confusion" exist.

(4). It will be found *by actual trial*, that *the greatest error* likely to be made in fixing a hair on the diaphragm, and inserting the diaphragm in the telescope entails an error or deviation of the horizontal hair, qm in figure, from the object-glass axis oC, (the amount of deviation will be denoted by k) of *less than* $\frac{1}{10}$ inch. $\therefore qm = k < \cdot 1$ inch.*

(5). Again, the smallest levels kept in the Central Instrument Depôt at Roorkee, which supplies all Northern India, have object-glasses of about 10 inches focal length, *i.e.*, the distance of the inner principal focus of the object-glass from its posterior surface (hereafter denoted by f) is *never less than* 10 inches. $\therefore f$ not $<$ 10 inches.

(6). Again, if ϕ be the angle of obliquity QCF (*Fig.* 2) of the axis of incident rays QC, *i e.*, inclination of their axis to the object-glass axis oC then (as is also easily seen by trial), the distance from the horizontal hair q to the object-glass is least for distant objects, and increases as the object viewed approaches. It follows that f(being the distance between the hair and object-glass for infinitely distant objects), is the *least* distance of q from the object-glass.

$$\therefore \tan\phi = \tan \text{QCF} = \tan q\text{C}o = k \div \text{C}m < k \div f, \text{ for } \text{C}m > f.$$

$$\text{Also } k < \cdot 1 \text{ inch, and } f \text{ not } < 10 \text{ inches.}$$

$$\therefore k \div f < \cdot 1 \div 10, \ i.e., < \cdot 01.$$

But for small angles $\phi < \tan\phi$, which is $< k \div f$ which $< \cdot 01$.

$$\therefore \phi < \cdot 01 \ \grave{a} \ fortiori.$$

This result is very important as it is entirely on account of *the smallness of the obliquity* ϕ "that Gravatt's method" practically fails.

First approximation to the locus of Q.

It is shown (Parkinson, Art. 112 and 113) on the approximate assumptions

(1). That the object-glass is indefinitely thin.

(2). That the obliquity ϕ is so small, that its square may be neglected that $\frac{1}{\text{C}q} = \frac{1}{\text{CQ}} + \frac{1}{-f}$, f being considered negative (Art. 102), because the object-glass is to be considered a convex lens (Art. 204).

* In the figure qm has been purposely exaggerated to avoid confusion.

Second approximation to the locus of Q.

It is shown (Parkinson, Art. 113, Cor. 4) on the assumptions

(1). That the object-glass is indefinitely thin.

(2). That the obliquity ϕ is so small that its fourth power may be neglected, that $\frac{1}{Cq} = \frac{1}{CQ} + \frac{1}{-f} + \left(1 + \frac{1}{\mu}\right) \frac{\phi^2}{-2f}$

Comparison of approximations.

Let CQ $= r$, QM $= y$, CM $= x$

$\therefore$ $Cq = \frac{kr}{y}$ from the similar triangles QCM, qCm.*

1st approximation $y = k - \frac{kr}{f}$.

2nd " $y = k - \frac{kr}{f} - \left(1 + \frac{1}{\mu}\right) \frac{\phi^2}{2} \cdot \frac{kr}{f}$.

Let δy be the difference of the ordinates y for *the same radius vector* r, then $\delta y = \left(1 + \frac{1}{\mu}\right) \frac{\phi^2}{2} \cdot \frac{k}{f} \cdot r$.

It was shown, para. (6), that $\phi < \cdot 01$, and $\frac{k}{f} < \cdot 01$.

Also μ varies from 1·67 for flint glass, to 1·5 for crown glass (Parkinson, Art. 162).

Assuming $\mu = 1{\cdot}6$, $\delta y < \left(1 + \frac{1}{1{\cdot}6}\right) \frac{(\cdot 01)^3}{2} \cdot r$

$< \frac{1{\cdot}625}{2} \times \cdot 000001 \times r$, *i e.*, $< \cdot 000008 \times r$.

Now with a 10 inch level, 300 feet is about the utmost limit of accurate reading.

$\therefore$ the greatest value of $\delta y < \cdot 000008 \times 300$ feet, an inappreciably small quantity.

With larger levels the limit of distance r increases say to 500 feet, but the small fraction $\phi^2 \frac{k}{f}$ decreases much more rapidly.

Thus it has been shown that within the limit of distance attainable in practice, the curve denoted by the second approximation differs from that denoted by the first approximation, by an inappreciable quantity, *even when the error* in position of the horizontal hair is *at its greatest.* It it obviously unnecessary to try any closer approximations, as far as the powers of θ are concerned.

* *N.B.*—Positive ordinates being measured downwards, the sign of k, *i.e.*, $mq = Cd$ is to be considered *inherently* negative throughout what follows.

It should be noticed that these results have been obtained on the approximate hypothesis, that the object-glass is indefinitely thin: it is not thought necessary to introduce the thickness of the object-glass into the investigation, as it greatly complicates it without materially affecting the above general conclusion.

It may now be shown that the locus of Q is a line differing inappreciably within the limits of practice from a straight line.

For $x = r \cos \phi = r\left(1 - \frac{\phi^2}{1 \cdot 2} + \frac{\phi^4}{1 \cdot 2 \cdot 3 \cdot 4} - \&c.,\right) = r$ nearly, *i.e., on the same assumption* as that by which the first approximation to the locus of Q was made, viz., that the obliquity ϕ is so small, that its square may be neglected.

Hence the first approximation *q.v.*, becomes

$$y = k - \frac{k\,r}{f} = k - \frac{kx}{f} \text{ or } \frac{x}{f} + \frac{y}{k} = 1,$$

which is the equation of a straight line whose intercepts on the axes are $CF = f$, and $Cd = k$, see *Fig.* 2.

That is the locus of Q is a curve differing within the limits of practice inappreciably from the straight line joining d to F (the external principal focus) which is *a fixed line* external to the telescope.*

It is interesting to note that the curve denoted by the second approximation, is really a very flat hyperbola, to which dF is tangent at F, of which one focus is C, and corresponding directrix a line through d, but it is beyond the scope of this paper to discuss this. It follows that the *quantity required to be measured* by Gravatt's method viz., the departure $Q_3N_3 \sim Q_2N_2 \cdot \frac{Q_1N_3}{Q_1N_2}$ of any one point seen as Q_3 from the straight line Q_1Q_2 joining the other two is *within the limit of practice quite inappreciable.*

Experimental Trial.

In order to test practically the correctness of the above theoretical investigations, and to settle if possible finally the question of the practicability or impracticability of discovering any error at all in the position of the horizontal hair of a level by Gravatt's Method, the following experi-

* This agrees with the assertion of para. 50, page 84 of Rankine's Manual of Civil Engineering quoted, though from a quite different line of reasoning.

ment was made by the author with the assistance of a student* of the Engineer Class, Thomason Civil Engineering College. It is necessary to state that great pains were taken to make every part of the observations thoroughly trustworthy, the object being to render the experiment a crucial test. At the risk of being prolix, the precautions taken will be detailed, so that the reader may satisfy himself as to the trustworthiness of the results. It will be premised, that throughout this experiment

(1). Only one levelling staff, a new one with a smooth flat brass foot was used: all error due to dissimilarity of division of different staves was thus avoided.

(2). The pegs subsequently alluded to were all wooden pegs, about 18 inches long, driven about 12 inches into firm ground, until apparently firmly bedded: the tops of all of them were rounded off, so that the flat foot of the staff might rest on only one and the same point on each occasion of its erection.

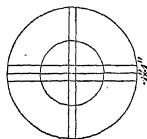
(3). All perceptible parallax of the field of view, and the hairs was carefully removed before every reading.

The correctness of position of the bubble of the large level was noted both before and after every reading of the staff: no readings were recorded unless the bubble had retained its position: the level used was however a very steady one.

(4). The correctness of the verticality of the staff at the time of every reading was watched by the author's assistant, who stood a few feet off the line of sight abreast of the staff for this propose.

A large new 20-inch Troughton level was chosen for the experiment: it was a very steady instrument: two horizontal hairs were added to the one originally on the diaphragm, each $\frac{1}{10}$-inch (by careful measurement) distant from the original horizontal hair, one above, one below it; (*see* diagram.)

Fig. 3.

The use of either of the new hairs produced a line of collimation, which was *obviously grossly different* from its proper position: in fact so great a deviation could not be made if moderate care were used in the insertion of a hair. A distance of 400 feet was chained carefully in one straight line on a fairly level piece of ground; 5 pegs, such as described

* Mr. W. P. Von der Horst.

above, were driven at L_1 L_2 L_3 L_4 L_5 (*see Fig.* 4,) at distances 0, 50, 100, 200 and 400 feet, respectively, from L_1.

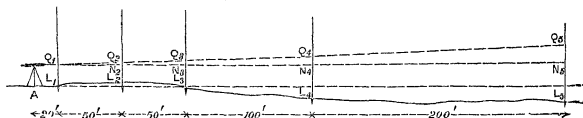
Fig. 4.

The points half way between the successive pegs were marked with arrows in the course of the chaining: the correctness of the bisection of the distance between the pegs was tested with a 50 feet tape, and the position of the arrows corrected. The staff was set up on each peg in succession, and the level set up at each of the middle points in succession with the aid of a plummet, and the staff read off on the equidistant pegs, the middle horizontal hair only being used throughout this operation. The results are recorded.

TABLE I.

Extract of Field Book of Observations to find difference of Level of tops of the five pegs.

Staves.	Staff Readings.		Difference of Level.		Reduced Level.	
	Back.	Fore.	Rise.	Fall.		
					·000	L_1
$L_1 - L_2$	4·034	3·764	·270	...	+ ·270	L_2
$L_2 - L_3$	4·013	4·358	...	·345	− ·075	L_3
$L_3 - L_4$	3 698	4 571	...	·873	− ·948	L_4
$L_4 - L_5$	3·288	5·185	...	1 897	− 2·845	L_5
		Total, ..	·270	3·115	− 2·845	

It will be admitted that the differences of level of the tops of the several pegs were thus correctly ascertained, all instrumental errors being eliminated in taking the differences of the several readings.

The level was then removed to a point A on the line produced, about 20 feet from it, it having been previously ascertained that this was the least distance at which a staff could be read distinctly, along with distinct vision without parallax of the hairs. The furthest staff, L_5, was thus about 420

feet distant; this was about the limit of distance admitting of accuracy of reading.

The staff was set up in succession on all the pegs, and readings taken on it at each peg *from each of the three horizontal hairs.* Whilst the level was at this point, the telescope was not touched, except from the necessity of focussing and correction of slight dislevelment caused by handling the focussing screw and eye-piece. The readings with each of the 3 horizontal hairs were recorded on separate field-book pages, the object being to ascertain, (if possible by this method), the amount of deviation from the object-glass axis of each hair. These readings are recorded in 3rd column, Table II.

TABLE II.

Reduction of readings on the five staves.

Hairs	Staff.	Distance from L_1.	Readings on Staves.	Height of top of peg above L_1 *see* Table I.	DEDUCED HEIGHTS OF POINTS VIEWED, VIZ., Q		Calculated heights above Q_1 of the straight line Q_1Q_2 produced	Departure of points viewed, viz., Q from the straight line Q_1Q_2.
					Above L_1.	Above Q_1.		
		ft.						
Upper Hair.	L_1	0	2·707	·000	2·707	·000	·000	·000
	L_2	50	2·107	+ ·270	2·377	− ·330	− ·330	·000
	L_3	100	2·123	− ·075	2 048	− ·659	− ·660	+ ·001
	L_4	200	2 341	− ·948	1 393	− 1·314	− 1·320	+ ·006
	L_5	400	2·89	− 2·845	·045	− 2 662	− 2·640	− ·022
Middle Hair.	L_1	0	2 793	·000	2·793	·000	·000	·000
	L_2	50	2·411	+ ·270	2·681	− ·112	− ·112	·000
	L_3	100	2 662	− ·075	2·587	− ·206	− ·224	+ ·018
	L_4	200	3 328	− ·948	2 380	− ·413	− ·448	+ ·035
	L_5	400	4·79	− 2·845	1·945	− ·848	− ·896	+ ·048
Bottom Hair.	L_1	0	2·872	·000	2·872	·000	·000	·000
	L_2	50	2·706	+ ·270	2·976	+ ·104	+ ·104	·000
	L_3	100	3·193	− ·075	3 118	+ ·246	+ ·208	+ ·038
	L_4	200	4 237	− ·948	3·289	+ ·417	+ ·416	+ ·001
	L_5	400	6·52	− 2·845	3·675	+ ·803	+ ·832	− ·029

N.B.—The correction for curvature and refraction amounts to only ·001 at 220 feet, and ·004 at 420 feet, and has been neglected.

Discussion of the Results of the Experiment.

The last column of Table II., shows the values of the quantity.

$$\left.\begin{array}{l} Q_3N_3 - Q_2N_2 \cdot \frac{Q_1N_3}{Q_1N_2} \text{ at staff 3,} \\ Q_4N_4 - Q_2N_2 \cdot \frac{Q_1N_4}{Q_1N_2} \text{ at staff 4,} \\ Q_5N_5 - Q_2N_2 \cdot \frac{Q_1N_5}{Q_1N_2} \text{ at staff 5,} \end{array}\right\}$$

viz., the departure of the points actually seen Q_3, Q_4, Q_5 from the straight line Q_1Q_2 produced,

which it has been explained is the resulting quantity upon the magnitude of which the *amount* of collimation error was to have been estimated.

The extremely small amount of this quantity, and also its irregular variation in the case of the upper and lower hairs (which are presumably *very* incorrectly placed) is particularly to be noticed: it is remarkable that this quantity is actually *greatest* in the case of the middle hair (which is certainly the most correctly placed of the three hairs).

Consider the probable errors of observation. it will probably be admitted that an error of ·001 might occur in the reading on staff 1 at 20′ from the level.

„	·002	„	„	„	2 at 70′	„
„	·01	„	„	„	5 at 420′	„

The first two combined would cause a possible error of ·003 in the length Q_2N_2 which would be exaggerated eight times in the height *calculated* from the proportion at staff 5.

The three errors combined might there produce a possible error of $8 \times (\cdot001 + \cdot002) + \cdot01 = \cdot024 + \cdot01 = \cdot034$ in the resulting quantity $\left(Q_5N_5 - Q_2N_2 \cdot \frac{Q_1N_5}{Q_1N_2}\right)$ at staff 5.

N.B.—It has not been thought worth while to consider the correction due to curvature and refraction as it amounts to only ·004 in the whole distance.

On the whole the author considers the calculated departures of Q_3, Q_4, Q_5 from the straight line Q_1Q_2 produced, to be chiefly made up by errors in observation, after making due allowance for which the residual quantity is either nil or *too small* to warrant trustworthy conclusions being drawn as to the correctness or incorrectness of position of *any* of the three hairs.*

* An experiment similar to the above (on a smaller scale) was performed with the same instrument, with the same set of hairs on a terraced floor on another occasion · the extreme distance of observation was only 120 feet, but the distances were much more carefully set out with a pair of 12 feet rods, on the level floor than was possible in the experiment in the open above detailed. The result was that the departure of Q_3 from the straight line Q_1Q_2 was still less appreciable with any of the three hairs than in the experiment detailed above.

Summary of Results.

The general conclusion both from the theoretical investigation and from the experiments is that the locus of Q, (*i.e.*, of all the points covered after correct focussing without parallax by the middle of the horizontal hair) is a line differing insensibly within the limits of practice from the straight line *d*F, which is *a line fixed relatively to the object-glass axis*, so long as the diaphragm screws are untouched, and that the application of Gravatt's Method will *necessarily entirely fail to effect its object*, *i.e.*, will not discover even a considerable error in altitude in the line of collimation.

Practical Conclusion.

It having been shown that all the points such as Q (which are covered after correct focussing by the middle of the horizontal hair), lie on the straight line *d*F, this line may be considered *the virtual line of sight*: (it must not be confounded with the *real line of sight* *q*CQ).

The *necessary* adjustments of the Dumpy, Troughton or Gravatt's Levels, will be only two.

(1). To set the large level parallel to the virtual line of sight.

(2). To set both these (after having been set parallel to each other) perpendicular to the vertical axis.

A simple way of effecting the former, is the following, slightly modified from one practised by Ensign P. Keay, Head Master, Thomason C. E. College.

To set the large level of a Dumpy, Gravatt, or Troughton level parallel to what has been above called the "virtual" line of sight. :—

Place two pegs, AB, at any convenient distance apart on a tolerably level piece of ground soft enough to admit of *easily* driving pegs. Bisect the distance between them carefully, and place the level to be adjusted over this middle point with the aid of a plummet. Level the instrument as well as its incorrect adjustment will allow. Direct the telescope on a levelling staff held upright on peg A, with the bubble at the middle of its run Record the reading.

Reverse the telescope, and direct it on the same staff removed to the peg B : if the bubble has left the middle of its run, bring it back to that position by the foot screws and record the reading on B.

It will be admitted that this process will give the difference of level of the heads of the pegs accurately. Now place the staff on the higher of the two pegs ; direct the telescope on it, bringing the bubble to the centre of its run if necessary. Now

tap this peg gently into the ground until the reading on the staff is *the same as* that on the staff when on the lower peg.

The heads of the pegs will now be on the same level.

Now remove the level on to the line AB produced at a sufficient distance from the nearer peg to admit of distinctly reading the staff when placed thereon.

Then (*a*) in the Dumpy or Gravatt Level :—

Direct the telescope in the same vertical plane as A and B, and bring the bubble to *any* convenient position (say the middle of its run), and again record the readings on the staff on pegs A and B, altering the focus and eye-piece as necessary, but watching the bubble to see that the telescope remains *steady* throughout. (Any change in position of the bubble to be corrected by the foot screws.) If the readings on the staves are (as will probably be the case) different, this shows that what has been above named the virtual line of sight of the instrument is not level.

Now tilt the telescope with the foot screws slightly in the direction indicated by the readings, (*i. e.*, object glass *down* if the reading on the *further* staff be the *greater* and *vice versâ*), and again record the readings on both staves, watching the bubble, which is of course in a new position, merely to see that the telescope remains steady whilst the focus is being altered. This operation must be repeated till the readings obtained on both staves are the same.

It will then be admitted that the "virtual line of sight of the telescope" is a level line. If the bubble be now, as will probably be the case, not in the middle of its run, it should be brought to the centre of its run by the adjusting screws in a Gravatt's or Dumpy Level.

And (*b*) in the Troughton Level :—

The level being a fixture, it cannot be *set* parallel to the line required, if not already so. But the latter, (viz., the "virtual line of sight") may be shifted so as to become parallel to the former, (viz., the level) by shifting the diaphragm, which alters the position of the line *gd* (*Fig.* 2), and therefore also of *d*F the virtual line of sight.

Direct the telescope in the same vertical planes as A and B, and bring the bubble to the centre of its run, and *retain it there* throughout the remainder of the process (by moving the foot screws if necessary). Record the readings on the staff held on pegs A and B, altering the focus and eye-piece as necessary.

If the readings on the staves are (as will probably be the case) different, this shows that what has been above named the virtual line of sight of the instrument is not level.

Now tilt that virtual line of sight by shifting the diaphragm slightly in the direction indicated by the readings, (*i. e.*, diaphragm *up* if the reading on the staff be the *greater*, and *vice versâ*), and again record the readings on the staves. This operation must be repeated till the readings obtained on both staves are the same.

It will then be admitted that the "virtual line of sight" is a level line, and therefore parallel to the large level.

This latter method is applicable also to the Dumpy and Gravatt level, but the former method will probably be found the easier in practice, as the foot screws are more easily handled than the diaphragm-screws.

2. The second adjustment must now be performed in the usual way.

Note upon an "Example" of application of Gravatt's Adjustment recorded in F. W. Simms' "Treatise on the Principal Mathematical Instruments," Sixth Edition, 1844.

At page 35 of the above, an "*Example*" is recorded, in which it is stated that the quantity $Q_3N_3 - Q_2N_2 \cdot \frac{Q_1N_3}{Q_2N_2}$ was ·11 of a foot, the distance L_1L_2 being two (Gunter's) chains, and L_2L_3 six (Gunter's) chains, a quantity far larger than the theoretic investigations indicate as possible, and also too great to be ordinarily due to observation errors: it seems (to the author) very unlikely that the horizontal hair of this instrument could have been so far out of position as the upper and lower hair used in the author's experiment (detailed), which had been purposely placed as far out of proper position as seemed possible, nevertheless the residual quantity is far larger than in the author's experiments.

This seems to require explanation * It is not stated whether the "Example" is merely *a numerical illustration* of the method, the actual figures being hypothetical, or whether it is a copy of *actual field observations*. The context of about half the Example decidedly points to the latter, and the context of about half is consistent with the former alternative. One sentence however seems to render the former conclusion more probable. The words in question are "The instrument being now placed at *d* (say five feet from *a*, but the closer the better)"

Had the example been taken from field observation, the position of the instrument would hardly have been mentioned in such a doubtful way. but the distance of five feet is *actually too small* to admit of correct readings being made, so that the example is either not from actual field observation, or else is an inaccurate one, and no argument as to the practicability of "Gravatt's method" can be drawn from the apparent sufficient magnitude (·11 of a foot) of the quantity from which the inference is to be drawn.

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* Simms' Treatise being considered an authority.

ADDENDUM.

An objection has been raised to the process here proposed for adjusting the Troughton Level, page 509 (b) *q. v.*, viz., "that this very process has been employed *with success* to *discover* and then *correct* the error in altitude of the 'line of collimation.'" It is scarcely necessary to point out to a reader who has understood the investigation given, that the process involves the same theory as that of "Gravatt's Method," and the success *supposed* to be obtained is as far as discovering or correcting any collimation error *wholly imaginary*.

It was *supposed* that if by *any* means (either by moving the foot screws *or* diaphragm screws) two points *known* to be *on the same level*, (at *different* distances from the object-glass) could be seen through the telescope, that, *therefore*, "the object-glass axis was level, *also* the middle of the horizontal hair was in that axis," *i. e.*, that there was no collimation error.

This, however, cannot be accepted *without adequate proof:* all that can be legitimately inferred (see the investigation in this paper) is that the "*virtual line of sight*," dF (see *Fig.* 2.) *is level.*

However, as experiment is more convincing to many, the author performed the following experiment with every possible care.

The level described on page 504 with the diaphragm mounted with three hairs, as in *Fig.* 3, before used, was used again. It will be admitted that the upper and lower hairs could not *both* be on the object-glass axis, (*i. e.*, that *one* of them at any rate involved a collimation error).

The process described on pages 508 and 509 was *very carefully* followed, as for a Dumpy or Gravatt Level (with the same precautions as on page 504), the distance of the level from A being 25 feet, and from B being 125 feet. It was found to be not only possible, but easy, *by the motion of the foot screws alone*, to tilt the whole telescope into two such positions

as to make *two equal readings on the two staves, i. e.*, to read along a level line, (1) when the upper hair *alone* was used, and (2) when the lower hair *alone* was used.

This experiment *conclusively* shows that the process proposed, (which was *supposed* to afford a means of discovering a collimation error,) does not warrant *any* inference as to the correctness or incorrectness of the line of collimation. All that can be inferred at the conclusion of the process is that "the virtual line of sight is level."

A. C.

No. XLVIII.

EXPERIMENTS ON ANDAMAN WOODS.

By J. BENNETT, C.E., *Executive Engineer, Port Blair.*

THE following Notes on the Botanical names, &c., of the trees of this List of "Andaman Woods" has been kindly furnished to the Editor by the Conservator of Forests in British Burmah.

1. (**A.**) PADOUK. (*Pterocarpus indicus*) Yields gum kino: there are two kinds in Burmah, the red and the white—the red furnishes the finer timber. It is plentiful in Tenasserim.
2 (**B.**) PYENMAH. (*Lagerstrœmia reginæ*) Abundant in the low lands of Burmah: good timber for boat building; keeps well under water, but not well adapted for house posts.
3. (**C.**) YOUAY-GYEE. (*Adenanthera pavonina.*) Yields hard tough wood: to be found on the Southern part of Tenasserim.
4. (**D.**) GANGUA.
5. (**E.**) THINGAN. (*Hopea odorata*) Abundant in Tenasserim, scarce in Pegu and Arracan: useful for boat building.
6. (**F.**) TOUNG-PEING. (*Artocarpus echinata* and *Chaplasha.*) Found in Tenasserim, where the Burmese value it for boat building.
7. (**G.**) BAM-BWAE. (*Careya arborea.*) Not much worth: plentiful in Pegu.
8. (**H.**) THIMMIN (properly Thitmin) (*Agathis loranthifolia.*) Plentiful in Tenasserim: used by carpenters for light work.
9. (**I.**) KANYEEN. (*Dipterocarpus alatus* and *lævis.*) The wood oil tree: valuable principally for its oil: plentiful in Burmah: will not stand wet, and very much subject to white ants. Makes very good charcoal.
10. (**J.**) KUPPALEE-THEET. (*Sonneratia?*) Not known: I think peculiar to the Andamans.
11. (**K.**) NABBHAY. (*Odina wodier.*) Not uncommon in Tenasserim: grows to 12 feet high. Wood red and hard, used for rice pounders, &c.
12. TEAK. (*Tectona grandis.*) Plentiful in Tenasserim and Pegu, scarce in Arakan. Also the Hamilton teak, a very inferior kind, is met with in Pegu.

RESULT of Experiments on the Stiffness of a few of the various Woods from the Andaman Forests, as made at Port Blair, January 1872.

No.	Burmese name.	Number of trials	Length in feet.	Depth in inches	Breadth in inches.	Deflexion in inches	Weight producing deflexion in lbs.	Average.	Breaking weight in lbs.	Constant a.	Average weight per cubic foot.	Plentiful or otherwise.	To what average size procurable.	Remarks
						ths					lbs.		Inches in diameter	
1. (A.)	PADOUK, ..	1	3	$1\frac{1}{2}$	$1\frac{1}{2}$	5 8	663	650	916	·0072152	$49\frac{1}{2}$	Plentiful	24	A very durable wood, and well adapted for almost every building purpose. Timber close grained and fibre compact and tough. Broke $\frac{1}{4}$th by compression and $\frac{3}{4}$th tensile strain. Fracture long.
		2	3	$1\frac{1}{2}$	$1\frac{1}{2}$	5-8	609		973					
		3	3	$1\frac{1}{2}$	$1\frac{1}{2}$	5-8	677		914					
2. (B.)	PYENMAH, ..	1	3	$1\frac{1}{2}$	$1\frac{1}{2}$	5-8	383	364	723	·0128895	41	Plentiful.	36	A light and rather tough wood, well suited for house building, for which it is much in demand. Timber close grained, fibre coarse and loose. Greatest deflexion $2\frac{5}{16}$th inch; broke as above, fracture very long.
		2	3	$1\frac{1}{2}$	$1\frac{1}{2}$	5-8	348		551					
		3	3	$1\frac{1}{2}$	$1\frac{1}{2}$	5-8	360		652					
3. (C.)	YOUAY-GYEE, ..	1	3	$1\frac{1}{2}$	$1\frac{1}{2}$	5-8	662	634	1115	·0073935	55	Moderate.	20	A first class wood, ranking with Padouk; is used extensively in buildings of every kind, is little liable to warp and is seldom attacked by white ants. Grain close and regular, fibre rather coarse. Broke as above with a fracture very long.
		2	3	$1\frac{1}{2}$	$1\frac{1}{2}$	5-8	635		1150					
		3	3	$1\frac{1}{2}$	$1\frac{1}{2}$	5-8	605		916					
4. (D.)	GANGUA, ..	1	3	$1\frac{1}{2}$	$1\frac{1}{2}$	5-8	766	712	1325	·0065866	70	Moderate.	16	A very hard heavy wood, and remarkably tough, but is liable to split and warp when badly seasoned. Is much in use for beams and girders. Grain close, and fibre coarse and loose. Tree attains a great height, from 90 to 100 feet. Broke as above, fracture long.
		2	3	$1\frac{1}{2}$	$1\frac{1}{2}$	5-8	708		1[illegible]13					
		3	3	$1\frac{1}{2}$	$1\frac{1}{2}$	5-8	661		1018					

5.	(E.) THINGAN, ..	1 2 3	3 3 3	1½ 1½ 1½	1½ 1½ 1½	5-8 5-8 5-8	469 519 608	532	581 861 959	·0088111	58	Moderate.	20	Wood extremely durable in any situation, and is much in demand as posts and girders. Grain close and fibre rather short. Broke ½ by compression and ½ tensile strain, fracture long.
6.	(F.) TOUNG-PEING, ..	1 2 3	3 3 3	1½ 1½ 1½	1½ 1½ 1½	5-8 5-8 5-8	354 326 322	334	554 547 449	·0140344	22	Moderate.	16	This a soft, light wood when fully seasoned, and is much used in building canoes ; stands exposure and resists the worm. Grain close and straight, fibre coarse.
7.	(G.) BAM-BWAE, ..	1 2 3	3 3 3	1½ 1½ 1½	1½ 1½ 1½	5-8 5-8 5-8	479 541 469	496	724 651 651	·0094443	56	Moderate.	20	A dark brown and rather heavy wood, but of an inferior nature ; is very brittle and soon decays, and is therefore little in use. Grain close and fibre short. Broke by compression, fracture very short.
8.	(H.) THIMMIN, ..	1 2 3	3 3 3	1½ 1½ 1½	1½ 1½ 1½	5-8 5-8 5-8	383 467 420	423	605 700 680	·0110728	34	Plentiful.	14	A pale yellow light wood slightly resembling pine ; much used as planks and for making boxes, packing cases, &c., but is not durable. Grain close and fibre fine. Tree tall and straight. Broke short ½ by compression and ½ by tensile strain.
9.	(I.) KANYEEN, ..	1 2 3	3 3 3	1½ 1½ 1½	1½ 1½ 1½	5-8 5-8 5-8	590 593 651	611	833 808 815	·0076677	49	Plentiful.	22	Wood rather heavy, but of a useless description for building purposes. The species is known as the "wood oil tree." Grain compact, and fibre coarse. Broke as in "Thimmin," fracture short.
10.	(J.) KUPALLEE-THEET,	1 2 3	3 3 3	1½ 1½ 1½	1½ 1½ 1½	5-8 5-8 5-8	783 780 794	786	1269 1241 1297	·0059663	66	Scarce.	30	Is a very durable, hard and heavy wood, but is not much in demand, being scarce and difficult to work, is well suited for edge tool handles and gun stocks. Grain very close, and fibre fine and compact. Greatest deflexion 2⅛th inch, broke at this ¼th by compression, and ¾ths by tensile strain, fracture produced very long.

No.	Burmese name.	Number of trials.	Length in feet.	Depth in inches.	Breadth in inches.	Deflexion in inches.	Weight producing deflection in lbs.	Average.	Breaking weight in lbs.	Constant a.	Average weight per cubic foot.	Plentiful or otherwise.	To what average size procurable.	Remarks.
						lbs.					lbs.		Inches in diameter.	
11. (K.)	NABBHAY, ..	1	3	1½	1½	5-8	348	343	530	·0136795	59	Scarce.	20	A close grained pale red wood, rather heavy and difficult to season, said to be a good wood for cabinet work. Broke short half by compression and half by tensile strain.
		2	3	1½	1½	5-8	358		567					
		3	3	1½	1½	5-8	322		536					
12.	TEAK, MOULMEIN,	1	3	1½	1½	5-8	442	447	718	·0106579	42	..	..	Used at one time for every purpose, but is now giving place to the use of local timber. Broke as above, fracture rather short.
		2	3	1½	1½	5-8	450		781					
		3	3	1½	1½	5-8	449		742					

NOTE.—The object of testing here the stiffness of imported teak, was, that a comparison might be made between itself and local wood.

In the experiments made, the weight in each case was applied to the centre. And for finding the constant a, the rule laid down in Tredgold's *Elementary Principle of Carpentry* has been adopted as in the following extract.

"This constant has been found experimentally by various writers, but differentally, modified according to the circumstances; some giving it "for beams fixed at one end, some when supported at each end, some taking the length in feet, others inches, &c. The author, in his former "edition, finds the constant a as follows, viz., the length is measured in feet, the other dimensions in inches; and the result is taken 40 times, "what the above formula gives, viz.,"

$$\frac{40 \times b \times d^3 \times \delta}{L^3 W} = a^*.$$

"And by this formula, the numbers or values of a, in the following pages, have been computed.

"Before these rules can be applied, the value of a must be obtained from experiments.

"It has been seen that the deflexion is as the weight and cube of the length directly, and as the breadth and cube of the depth inversely "and consequently, that the stiffness is as the latter directly, and as the former inversely; that is, the stiffness is as $\frac{b \times d^3}{L^3 \times W}$.

"Supposing, therefore, the deflexion δ to have been obtained experimentally in any material, we should have $\frac{b \times d^3 \times \delta}{L^3 \times W}$ = a constant "quantity, which being given, the deflexion in any other case might be found."

The black letter following each number in this paper has been entered for the sake of reference, as it corresponds with the letter branded on each specimen of the several descriptions of wood, of which those above named are samples, forwarded to Calcutta in September last by direction of the Government of India.

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Executive Engineer, Port Blair.

(Sd.) W. CAUSLEY,
Supervisor, P. W. D.

* *Vide* Paper XLIV. This $a = \frac{40}{E_d}$.—From this equation therefore $\left[a = \frac{40}{E_d}\right]$ the value of a may be found for any of the timbers in Article XL, in which the value of E_d is given: and conversely in this paper the value of E_d for any of the woods mentioned can be found from the equation, $E_d = \frac{40}{a}$.—[ED].

No. XLIX.

BULL'S ANNULAR KILN.

Description of a Kiln for burning bricks by a new and improved method, invented and patented by W. BULL, ESQ., *Resident Engineer, Oudh and Rohilcund Railway.*

THE consumption of wood in burning bricks for the large public works now being carried out in India, is gradually denuding the country of its finest trees, principally mangoe. That this is a matter for regret will I believe be generally allowed, and any method resulting in a diminished consumption will I feel sure benefit the country generally beyond the mere question of economy, (itself a matter for serious consideration.) The method or principle which, with its practical application, is described in this article, will be found to have realized the desired result, to an extent which will depend in a great measure on the care taken in carrying it into practice.

The accompanying plan with a short description will explain this method. It is applicable either to an annular kiln, suitable for continuous burning, or to one of oblong form. When the necessary space can be obtained, the former will be found the better plan.

A length, say of 50 feet, having been built, loading can if required, be commenced, and until the entire circle is completed the operations of building, loading and burning can be carried on simultaneously.

The saving in time resulting from this is obvious, as the supply of pucka bricks can be commenced three weeks after first starting operations,

and it will be found that six flues containing 14,400 bricks can with ease be fired daily; and—with a percentage of 66 only of 1st class bricks—a single kiln is capable of turning out 3 lakhs per month. The length mentioned having been built, a wall should be run up between two flues at one end, and loading commenced. The method of "setting" shown in the plan, is suitable for bricks $8\frac{3}{4}'' \times 4\frac{1}{4}'' \times 2\frac{3}{4}''$. If a larger size be required, the number of air passages and concentric walls can be reduced. In the plan given, the walls should be 4 inches apart, the spaces between the outer walls and the casing of the kiln being a little more.

The concentric walls are covered by a brick-on-edge, the length running across the kiln, every alternate row of which spans the air passage; the intermediate bricks being on the walls, thus giving the open work, called by the natives "jingree." On this open course, a brick flat should be set as close together as possible, and flushed over with soft mud, to effectually close all interstices.

Between the 10th and 11th flues for a space 1·6′ broad, the open brick and brick flat should be omitted for the chimney, which may either be of sheet iron as shown in the plan, or be built up of loose bricks, which can be taken down and used for the next chimney as required. A compact layer of ashes or earth 9 inches thick, should now be spread over the whole up to the chimney, and firing commenced in the first two flues. It should be carried on as briskly as is consistent with a complete combustion of the fuel. If forced beyond this, an accumulation of charcoal in the flues, and a greater expenditure of fuel is the result. After six hours a third flue should be opened, and again every successive 6th hour another, for the first two days. Forty-eight hours after commencing firing, the flues can be opened every four hours, and this rule can be continued regularly.

The two first flues fired will be ready in from 36 to 48 hours, but after the second day, as the bricks in advance of the flues being fired, and the kiln itself, get thoroughly heated, it will be found that 24 hours' firing will be sufficient; and there will thus be six flues firing at one and the same time.

If the wood be dry and firing well attended to, this time will be decreased and the number of flues proportionately less. In the meantime loading has been going on, and by the time six flues have been fired, should have advanced far enough beyond the first chimney to put up a

second, the operation of covering in being repeated in the same way as before. This being done, the first chimney should be removed, and the space covered up like the rest. This is to be carried on regularly, bearing in mind that the firing should never be allowed to come within the length of four flues from the chimney. After the draught has been thoroughly established, the mouths of the ash flues can be closed up with loose bricks, but not plastered until the 50th flue has been fired. They can then be entirely closed and the air for the combustion of the wood can be supplied by opening the mouth of the 20th ash flue in the rear of the firing flues, and successively as each flue is closed, another ash flue can be opened, and the one last opened, closed. By the time the 90th flue has been fired, unloading can be commenced, the ashes having first been taken off, and used on the part being loaded, which will by this time, have advanced within a short distance of the part first fired; the lower flues can also be opened up to the 50th in the rear of the firing, and this should be done regularly. The kiln now is in full operation, which can be continued all through the working season unless stopped by rain. If, however, in this case the loading is well in advance of the firing, the latter may be continued at a diminished rate, say by opening a flue every six hours or even less often, as it is a great object not to stop entirely.

One man on each side, with a change for the night, will be found sufficient for firing the kiln; with an experienced man to superintend the final closing of the flues. The firing is under easy control, and the time for finally closing the flues can be known by the amount of settlement. About two inches all over will be found sufficient. If one part settles more than another, the firing should be lessened in that particular part. The ashes or earth should have been spread evenly, and the settlement can then be seen by using a straight edge across the top. By taking a sample brick from the top of the outer wall, it can also be seen when the bricks are thoroughly burnt. It will be found in practice that the flues on the inside of the circle will be ready before those on the outside, and in the proportion the lesser length of the inside concentric walls bears to that of the outside. There will at times, therefore, be a flue less firing on the inside of the circle.

The following statements will show results from a section of ten flues in actual practice, the number of hours fired, the quantity of fuel consumed, and the cost of the out-turn. The ten flues chosen are somewhat under

the average as regards result, having been fired when the kiln was quite new, and damp. After passing the part first fired, there is a sensible decrease in the consumption of fuel, and corresponding saving in cost.

No. of Flue in order of firing	Hours fired.	Wood consumed	Bricks in each.	Out-turn.				Remarks.
				1st class.	2nd Class.	3rd Class	Ballast.	
51	22	23	2400					The wood used was dry mango wood, taking 5 cubic feet closely stacked, to the maund.
52	32	23	2400					
53	26	23	2400					
54	25	23	2400					
55	18	23	2400	18,500	2,400	2,750	350	
56	17	23	2400					
57	27	23	2400					
58	13	23	2400					
59	9	23	2400					
60	8	26	2400					

STATEMENT SHOWING COST.

	Rs.	A.	P.
24,000 kucha bricks $8\frac{3}{4}'' \times 4\frac{1}{4}'' \times 2\frac{3}{4}''$ at Rs. 1-4-0, Loading the same, at Rs. 0-6-0, ... Firing do., at Rs. 0-2-0,.. .. .. Unloading do., at Rs. 0-4-0,..	48	0	0
233 maunds of wood, at Rs. 24, ...	56	0	0
Cost of kiln per 1000 fired in one season, at Rs. 0-4-0	6	0	0
Superintendence, &c., at Rs. 0-4-0, ...	6	0	0
Total Rs., ..	116	0	0
which divided proportionately gives			
18,500 1st class bricks, at Rs. 5-4-3·2, per 1000,	98	7	3
2,400 2nd " " " 4-0-0 "	9	9	7
2,750 3rd " " " 3-0-0 "	8	4	0
350 Ballast at Rs. 2,..	0	11	2
Total Rs., ..	116	0	0

The kiln can be built either of mud with kucha brick flues and floor-

ing, or with kutcha bricks set in mud, entirely. In the latter case, it will cost about Rs. 450, and this distributed over a season's burning, taking the minimum quantity at 300,000 bricks loaded per month for six months will be 4 annas per thousand. In addition to great economy, there are other advantages resulting from burning bricks by this method, viz., perfect regularity and system in working, an absolute certainty of a fixed number of 1st class bricks daily, as long as the kiln is in operation :—ease in firing, the strongest winds having no effect on it:—a minimum of breakage and distortion :—and thoroughly annealed bricks, from the fact of their being completely covered in, and allowed to cool very slowly.

It will be found an advantage to use a moveable sheet iron chimney as shown in plan, to assist the draught, but if not available, a temporary one can be built up as before mentioned, and need not of necessity be more than 3 feet high. In firing, the mouths of the flues should be kept open only just sufficiently long to admit of the necessary quantity of wood being supplied, then closed by the earthen dummy, and plastered with soft mud. The small hole in the centre of the dummy will, will allow the men firing to see when more fuel is required.

Tiles of all sorts which can be "set" on the concentric walls, can be burnt to perfection in this kiln, and if placed in favorable parts, can be turned out with scarcely a single failure, owing to the small height of the kiln, and consequent light load, and minimum of breakage.

In conclusion, I have no hesitation in stating, that the bricks burnt by this method, are *on the whole* more thoroughly and uniformly burned than in any other kiln I know of in use in India.

W. B.

PROFESSIONAL PAPERS

ON

INDIAN ENGINEERING.

[SECOND SERIES.]

EDITED BY

MAJOR A. M. LANG, R.E.,

PRINCIPAL, THOMASON C. E COLLEGE, ROORKEE.

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1872.

JAMES JOHNSTON, SUPERINTENDENT.

CONTENTS.

ERRATA.

Page 523, line 12, *for* " patents," *read* " patients."
" 534, " 18, *for* " particlar," *read* " particular."
" 537, " 26, *for* " stress—intensity," *read* " stress-intensity "
" 538, " 8, *for* " *Muschenbrock*," *read* " Muschenbrock."
" 540, last line, *for* " No. LVII.," *read* " No. LII."
" 547, line 1, *for* " nders," *read* " cinders."
" 547, last line but one, *for* " notgood," *read* " not good."
" 548, line 4, *for* " ft. c.," *read* " Ft. C."
" 573, " last but one, *for* " les," *read* " less."
" 574, " 13, *for* " one," *read* " one's."
" 580, " 15 and 19, *for* " *o*," *read* " 0."
" 582, " 3, 4, 5, 9, 10, *for* " *o*," *read* " 0."
" 583 " 9, *for* " $\frac{\varpi x^2}{2}$," *read* " $\frac{wx^2}{2}$."
" 586, " 9, *for* " it it," *read* " it its."
" 590, " 13, *for* " an ϕ," *read* " tan ϕ."
" 592, " 24, *for* " initated," *read* " imitated."
" 596, " 5, from foot, *for* " approxmate," *read* " approximate."
" 608, " 17, *for* " analyses," *read* " analysis,"
" 615, " 27, *for* " Aigulle," *read* " Aiguille."
" 617, " 5 from foot, *for* " sufficent," *read* " sufficient."

No. L.

MAYO HOSPITAL, LAHORE.

[*Vide* Photograph, and *Plate Nos.* XLIII. and XLIV.]

Communicated by W. PURDON, ESQ., M. INST. C.E., F.G.S., *Supdg. Engineer.*

Photograph executed by RAI KUNHYA LAL, ASSOC. INST., C.E., *Exec. Engineer.*

THIS building has been lately erected at Lahore, under the Superintendence of Rai Kunhya Lal, Exec. Engineer, Lahore Division, from the designs of Mr. W. Purdon, Supdg. Engineer. It is considered a handsome building, and well adapted for the purposes for which designed. The following estimate shows the cost at which the building has been actually constructed: and as such is a record of the cost of such works in Lahore, and the neighbourhood, in the years 1871-72.

The above building is situated behind the Sudder Bazar, Anarkullee, Lahore, on the elevated piece of ground to the south-west of Ruttun Chund's Serai. Its style of architecture is "*Italian*," and in designing it, the general principle of hospital accommodation for natives, contained in Government of India's Circular, No. 19, of 5th March, 1866, has been adhered to, with such slight modifications as the special nature of the building demanded, so as to suit it for the purposes for which it is required at Lahore, viz., a School of Instruction, as well as an hospital.

The building is double-storied, the principal facade is 408 feet long, the breadth being $51\frac{1}{2}$ feet.

It consists of four main wards, each $115\frac{1}{2}' \times 22\frac{1}{2}' \times 16'$ (two in the lower, and two in the upper, floor), with dispensary, out-patients' room,

clinical clerk's rooms, and room for private examination, in the lower floor of the centre part of the building; operating room, store-rooms, house surgeon's rooms, and room for operating instruments, in the upper floor of the same; wash-houses, and in-door privies, (the former fitted with different kinds of baths for patients,) in the projections at the four corners, which are quite distinct from the wards, but connected to them by a verandah, which acts as a sort of covered passage; thus all offensive odours are cut off from the wards.

Access to the upper floor of the building is given by a flight of steps 12 feet wide, (sufficient for taking beds up and down,) situated on one side of the centre part of the building.

Flights of narrow steps are also constructed outside the building, for the sweepers and bheesties to get access to the upper floors of the wash-houses and privies.

In the centre of the building is a hall, 18′ × 18′ inside, with a four-storied tower over it, surmounted with a dome, terminating in a stone pinnacle, and iron finials, gilt at top. The height of the tower above floor level, is 107 feet, and above the adjacent ground 120 feet, which is nearly as high as the minarets of the "*Badshahee Musjid*," the highest building in the City of Lahore.

The wash-houses and in-door privies have also a third storey over them, with open archways, covered with a slate roof of equable slope, terminating in a point.

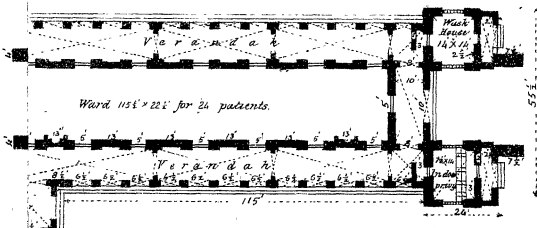
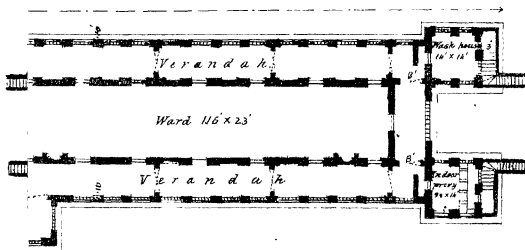
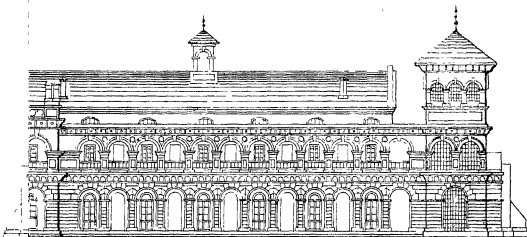
The building is constructed of the best mortar masonry, faced with dressed bricks; the foundations are 8 feet deep, 3 feet of which consist of the best concrete, well consolidated. The floors are made of dressed square tiles, set in lime, on concrete, with fine joints. The main building has a slate roof, supported on strong trusses made of deodar wood; the verandahs are roofed with beams, kurries, and planks, of the same wood, having lime terrace over the planks, on a layer of small bricks laid flat.

Upper floors of main wards are also tiled, supported on burgahs and trusses of deodar wood, with iron tie-rods; those of centre rooms and verandahs are arched, the latter having tie-rods to carry the thrust.

The main outer cornice is of red sandstone, properly cut, and supported on stone corbels.

The doors are made of the best deodar wood, varnished.

The upper wards and centre rooms have neat boarded ceilings of

Wash house 14' x 14'
Verandah
Ward 116' x 23'
Verandah
Indoor privy
Wash House 14 x 14
Verandah
Ward 115½' x 22½' for 24 patients.
Verandah
Indoor privy
115'
24'
55½'
60½'

deodar wood, pierced with holes for ventilation, which open into the triangular space between the ceiling and the rafters of the roof, which is ventilated by means of windows in the gable ends, and wooden towers in the middle, fitted with venetians, which communicate with the air outside.

The centre rooms are ventilated by means of round windows in the walls, close under the wall plates.

The drainage from the roof is passed through iron water spouts fitted into holes in the parapet wall, one over every pillar, and the space round the building, for a width of 18 feet, is metalled with kunker, with a good slope outwards, so as to lead the drainage away from the building.

The building was originally designed for native patents only, but a portion of it is, now, partitioned off, for the use of European patients also.

The building faces north and south, and affords accommodation for 104 patients, giving 108 superficial feet of space, and 1,732 cubic feet of air, per patient.

The out-buildings consist of a ward 20′ × 20′ for contagious diseases, with verandahs round it; dead house 18′ × 18′ with a verandah on the west face; cook-house (having separate compartments for Hindoos and Mahomedans), privies, servants' houses, and an out-door lavatory.

A low compound wall of pucka masonry, with ornamental iron gates, surrounds the buildings.

The above buildings have cost as follows:—

	RS.	A.	P.
I.—Main Hospital covering an area of 26,000 superficial feet, @ about Rs. 5-6-0 a foot, ...	1,40,204	11	5
II.—Out-houses do., 8,361 superficial feet, @ about Rs. 1-7-0 a foot,	11,355	9	2
III.—Compound wall, including iron gates, ...	5,977	15	1
IV.—Miscellaneous charges, levelling ground, and making approaches, &c., ...	1,403	0	0
Total Rs., ...	1,58,941	3	8

Of this sum, Government gave a grant of a lakh of rupees from Imperial funds, and the rest was met from Local funds, the Municipality of Lahore paying Rs. 26,697.

The late Viceroy inspected the hospital on the 18th November last, and was pleased to signify his consent to its being called "*The Mayo Hospital.*"

The accompanying plan illustrates the above, and the abstract gives the

actual quantities of work, in the different buildings, together with the working rates and cost.

Extract from Report of the Lahore Medical School for the year 1871-72.

The main building consists of a centre facing north and south, and of two wings placed parallel to the centre, but a little behind it to secure free ventilation.

Each wing is occupied by two large wards, one on the upper story and the other on the lower floor, each of which is constructed for 24 patients, or 12 on each side.

Each ward measures 115½ feet long by 22½ feet wide, and is 18 feet high; so that its total cubic contents are 46,777 cubic feet, and its superficial area is 2,598 feet.

Hence the wall space for each bed is nine and a half feet, the superficial area is 108 square feet, and the total cubic space for each is 1,949 cubic feet, or, if the beds and the persons are deducted at the rate of ten cubi. feet for each bed, and three for each person, there will still be 1,936 cubic feet of air available for each patient; while the amount laid down as necessary for hospitals in the tropics is only 1,500 cubic feet for each person.

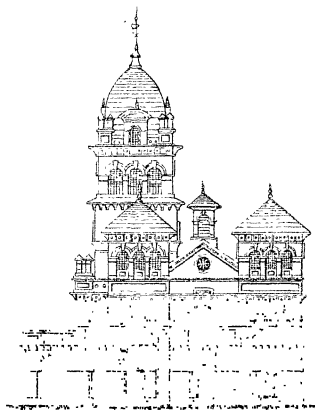
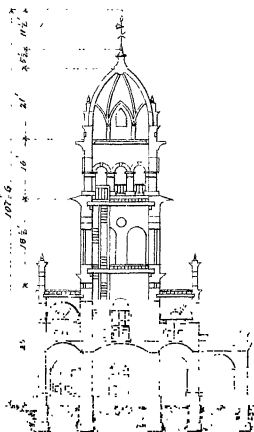
The arrangements for ventilation are also most excellent. Each ward has seven doors on each side and one at each end; each door measures 4 feet 2 inches in width and 7 feet nine inches in height; so that the opening of each equals 32 square feet 3 inches; and, as there are 16 doors in every large ward, the total amount of space for the admission of fresh air is 416 square feet.

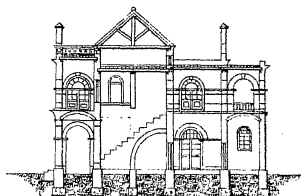
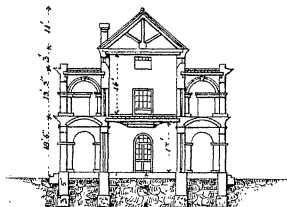
It is usually considered that 3,000 cubic feet of air are sufficient for a person in one hour; so that 72,000 cubic feet would be required for the 24 patients in each ward. This would be supplied by the passage of 170 feet of air through all the doors per hour, or of 340 feet, if half of the doors were only used; but this would necessitate the passage of only 5 feet 8 inches a minute, or little more than 1⅛-inch per second, an amount which is quite imperceptible and would cause no draught. Besides the doors, there are ventilators above each door, measuring 9 inches by 4 feet 2 inches, and two openings in the lower wards near the ceiling measuring 9 inches by 16 inches, which lead into the upper verandah.

In the upper wards the ventilation is effected through the ceiling itself,

Mayo Hospital, Lahore.

SECTION ON C. D.

SIDE ELEVATION.

SECTION ON A. B.

SECTION ON E. F.

Scale, 40 feet = 1 inch

10' 5 0' 10' 20' 30' 40' 50' 60' 70' 80' 90' 100' 110' feet.

which is boarded over at the commencement of the slope of the roof, and each ceiling contains 12 circular ventilators about 1 foot in diameter, each closed by perforated zinc.

The empty triangular space between the tiles and the boarded ceiling keeps the upper wards comparatively cool, even in the hottest weather, and it has ventilators at each end and a ventilating turret in the middle.

There are two fire places in each ward, in which wood was burnt during the winter nights. These kept the air of the ward always above 58° F., which is the usual temperature of a house in Lahore during the frosty weather.

Access to the upper floor of the building is afforded by a stair-case, 12 feet in width, and quite straight, to facilitate the carriage of beds up and down. There are also smaller stair-cases in the towers at the end of the building for the sweepers and bheesties.

The lower wards are allotted to native male patients—that on the west side to Mahomedans, and that on the east to other sects. Of the upper wards the one most remote from the public stair-cases has been filled with female patients; while the west upper ward at present is occupied by European male patients, of whom from three to six are generally present.

The centre of the building is divided below into the dispensary and medical store-room; also the rooms for the examinations of out-patients; of which there are three, one for medical cases, one for surgical, and one for opthalmic cases. There is also a room for the private examination of patients, and the microscopical and chemical examinations of the products of disease.

In the upper floor of the main building are contained the general store-rooms and the wards for eye-patients, the windows of which are darkened by blue paper; also apartments for the resident clinical clerks; while the north verandah is rendered available for an operating room by the insertion into one of the arches of a piece of plate glass, and measuring 3 feet by 7 feet: this affords a clear upper light at all times of the year.

There is also a ward for contagious diseases, separated from the main hospital by a wall; it consists of a large room ventilated by four doors and a skylight above. This has been used lately for several small-pox cases, and other diseases. This room is 20 feet in every direction, and is ventilated by an upper sky-light as well as by the four doors.

ABSTRACT ESTIMATE.

I. Main Hospital.

c ft.		RS,	A.	P.
94,334	Excavation of foundation, at Rs. 3 per 1000,	283	0	0
39,373	Concrete work, at Rs. 10 per 100,	3,937	9	0
47,275	Pucka masonry of foundation, at Rs. 15 per 100,	7,091	2	3
17,075	Pucka masonry of plinth, at Rs. 22 per 100,	3,755	10	9
179,489	Dressed pucka masonry of superstructure, at Rs. 31-2-5 per 100,	55,910	5	7
2,360	„ „ „ of upper part of tower at Rs. 33-3-9 per 100,	784	5	8
s. ft.				
21,376	Tiled floor, at Rs. 14-2-8 per 100,	3,028	1	7
9,789	Arched floor, at Rs. 34-15-1 per 100,	3,420	10	10
10,720	Wooden floor, at Rs 74-15-11 per 100,	8,039	2	5
9,765	Flat terrace roof, at Rs. 59-15-10 per 100.	5,858	1	0
13,956	Slate roof, 14 to 23 feet span, at Rs. 127-2 8 per 100,	17,747	5	5
1,400	Zinc covering of tower, at Rs. 20 per 100,	280	0	0
53,818	Pucka plaster inner, including white-washing, at Rs. 3-12-9 per 100.	2,044	5	4
8,288	Boarded ceiling, at Rs. 0-6-3 per foot,	3,208	5	9
6,374	Doors and windows, at Rs. 1-1-6 per foot,	7,029	6	7
85	Venetians, at Rs. 1 per foot,	85	0	0
r. ft.				
1,465	Stone cornice, at Rs. 1-3-11 per foot,	1,822	6	0
No.				
894	Stone brackets for cornice, at Rs. 8 each,	7,151	10	6
r. ft.				
232	Inner cornice, at Rs. 0-4-0 per foot,	58	4	9
772	Railings of archways of upper story, at Rs. 1-3-1 per foot,	920	10	0
8	Privy screens, at Rs. 3 each,	24	0	0
2	Wooden ladders (stair-cases in the tower, at Rs. 149-12-2 each,	299	8	4
r. ft.	Outer cornice, at Rs. 0-8-0 per foot,	1,513	7	4
4	Fire places, at Rs. 24-15-3 each,	99	13	1
s. ft.				
172	Punkahs, at Rs. 0-8-0 per foot,	86	0	0
2	Ventilating shafts, at Rs. 200 each,	400	0	0
1	Stone pinnacle, at Rs. 25,	25	0	0
s. ft.				
800	Red painting, at Rs. 2 per 100,	16	0	0
1	Large iron finial with gilt letters, &c., at Rs. 199-3-6,	199	3	6
r. ft.				
312	Ornamental parapet, at Rs. 2-8 per foot,	779	15	5
s. ft.				
442	Large glazed doors in the upper verandah, at Rs. 0-12-10 per foot,	355	0	0
1	Plate glass for eye examination, at Rs. 300,	300	0	0
	Carried over,	1,36,553	6	10

		RS.	A.	P.
	Brought forward,	1,36,553	6	10
rg. ft. 48	Railings in doors of upper and lower story, at Rs. 0-7-11, per foot,	23	13	0
s ft. 538	Shelves in dispensary and store room, at Rs. 0-3-0 per foot,	100	0	0
	Total,	1,36,677	3	10

ORNAMENTAL FINISHINGS.

		RS.	A.	P.
c. ft. 1,324	Fine dressed pucka masonry, including ornamental mouldings &c., at Rs. 50-8-2 per 100,	668	12	4
4	Ornamental tops to above, at Rs. 5-13-7 each,	23	6	4
s. ft. 1,710	Wire gauze, including frames, at Rs. 0-7-3 per foot,	777	12	0
200	Ornamental railings of iron for ditto, at Rs. 2-0-0 per foot,	400	0	0
1,292	Pucka Plaster of soffit of dome rubbed smooth, and executed with kunker lime (burnt with charcoal) with stone lime mixed in it, including also cost of high scaffolding for the work at Rs. 11-14-8½ per 100,	153	15	10
8,445	Varnishing boarded ceiling of upper rooms, at Rs. 1 per 100,	168	14	4
5,197	Blue painting of lower wooden floors of wards, at Rs. 4 per 100,	207	0	0
No. 93	Hooks with iron straps at Rs. 1 each,	93	0	0
32	Sign boards, at Rs 0-15-11 each,	31	14	0
4	New openings opened in the side walls, and fitted with perforated zinc sheet frames (large ones), at Rs. 7 each,	28	0	0
4	Ditto ditto, (small ones), at Rs. 5 „	20	0	0
70	Iron water drips for the roof, at Rs. 2 each,	140	0	0
c. ft. 3,360	Concrete work under ditto, at Rs. 11-5-0 per 100,	380	12	9
s. ft. 60	Altering windows at the back, at Rs. 1 each,	60	0	0
2	Openings to be enlarged, and sides rebuilt with pucka masonry of dressed bricks, at Rs. 7 each,	14	0	0
mds. 3	Copper plates, 3½″ × ⅛″, at Rs. 50 per maund,	150	0	0
6-10	Iron bar, 4″ × ½″, at Rs. 8 per maund,	50	0	0
	Contingencies,	160	0	0
	Total for Main Hospital,	1,40,204	11	5

II. OUT-HOUSES.

	RS.	A.	P.
Ward for contagious disease,	1,800	11	4
Dead house,	3,168	11	1
Cook house,	2,597	3	6
Servants' houses,	2,164	3	11
Carried forward,	9,730	13	10

	RS.	A.	P.
Brought forward,	9,730	13	10
Chowkeedar and durwans' houses, ...	176	0	4
Out-door lavatory, ...	551	4	10
Large privy, ...	395	2	1
Small privy, ...	202	4	1
Total for out-houses, . . .	11,355	9	2

III. COMPOUND WALL, &c.

Compound wall including iron gates, ...	5,977	15	1

IV. MISCELLANEOUS CHARGES.

Levelling ground, making approaches, &c., ...	1,403	0	0
Grand Total Rupees, ...	1,58,941	3	8

Abstract.

I.	Main Hospital, ...	1,40,204	11	5
II.	Out-houses, ...	11,355	9	2
III.	Compound Wall, &c, ...	5,977	15	1
IV.	Miscellaneous charges, ...	1,403	0	0
	Total Rupees, . .	1,58,941	3	8

K. L.

No. LI.

BULL'S SLEEPER AND FISH-PLATE JOINT FOR PERMANENT WAY.

[Vide *Plate* XLV.]

Description of a new style of Sleeper and Fish-plate Joint for Permanent Way. Designed and patented by W. BULL, ESQ., *Resident Engineer, Oudh and Rohilcund Railway, Lucknow.*

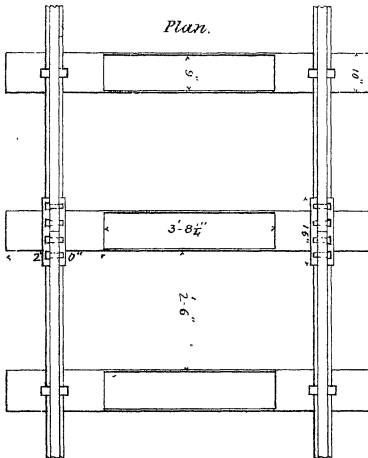
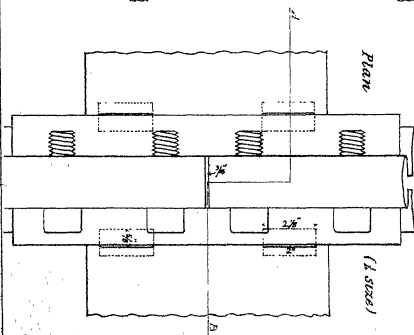
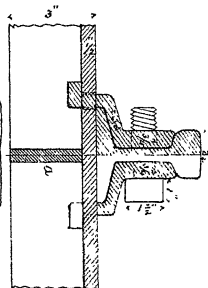
So many Engineers of standing have written and published largely on the subject of permanent way, and so many improvements and alterations have been suggested and carried out from time to time, that it is difficult to judge to what extent anything now brought forward is original, or merely a modification of some thing which has been tried before. As far as I can ascertain, the plan I now propose to give a description of, is original in all the parts for which originality is claimed, and if it be considered worthy of a trial, experience will show the value if any, which is to be placed on it.

It is in connection with the bearing parts and joints of the rails, or the parts by which the maintainence of a line of Railway is chiefly affected. The rail I look on as an exhausted subject, and when there are several good sections to choose from, it becomes more a question of manufacture, than the superiority of one particular kind over another. The kind of sleeper proposed is best suited for a flat-bottomed rail, and if the double headed rail be used, a cast or wrought-iron chair would be necessary. It is shown in the accompanying sketch, suitable for a 5½ foot gauge.

A great advantage it is hoped may be gained from the use of this style of sleeper is, that 90 per cent. more or less of the ballast usual-

ly required will be dispensed with, and I would only use it immediately under the sleeper itself, to be supplied at the ends, and at the opening in the middle. In the many different kinds of permanent way in use, the only advantage gained by the use of a complete layer of ballast, not obtainable from an equal quantity of earth or clay filling, is that of getting clean unmixed material for packing up when required, and it is only a very small portion which is thus used. In every other respect, on embankments in particular, it is a disadvantage to have a loose open material, which allows rain water to run through it and collect in pools underneath, causing the material of which the bank is composed to be gradually worked up into a state of soft mud, and the settling down of the rails to a much greater extent than is due to the subsidence of the bank itself, which if well constructed is sufficiently consolidated after two or three rainy seasons to bear the permanent way, with but very slight settlement, if care be taken with surface drainage. It may be said that the "Camber" given to a bank, will sufficiently throw off the water which percolates through the ballast, and doubtless it would if it remained as originally constructed, but such is never the case, as there is always a depression in those parts which have to bear the weight of the rails with the load they have to carry. Any bank, from which permanent way has been removed after some years, will be found of a most irregular surface; and the outside which has had no weight to carry, will be always the highest, particularly if the bank has been in the first place badly made, and owing to the great settlement the ballast has required to be banked up with earth, as is often done.

By the plan proposed, the rain water which would otherwise find its way as before said, to the depressed parts of the bank, and injuriously affect the level of the rails, would be almost entirely thrown off. After "linking-in" on the formation, the rails should be lifted, and levelled by packing at the ends, and open parts of the sleepers between the rails. Allowing for a six inch lift, which should take the depressions out of the worst constructed bank, we should require 9′ × 16″ × 6″ (allowing for ballast spreading at the bottom), or six cubic feet for each sleeper, or per chain of 100 feet, 180 cubic feet, in place of 1500 cubic feet, which is the average quantity required for a 5½ foot gauge. The ballast I would propose to use, would be a mixture of sand and fine kunkur, or any other small ballast, and this if carefully filled into the open part of the sleeper

BULL'S PERMANENT WAY.
Section.
12'-0"
7'-8¼"
5'-6"
Scale, 3/8" = 1 foot
Plan.
9"
10"
3'-8¼"
16"
2'-0"
2'-6"
Elevation.
Plan
(½ size)
3"
Section through
(½ size)

between the tie-bars, would almost entirely throw off the rain. The very ·ge saving in ballast thus caused, would materially affect the cost of a line of Railway. Between the sleepers I would fill in the same material as that composing the bank. It should be carefully filled in and consolidated, to the section shown in the plan. After a Line has become thoroughly consolidated, the rails might be banked up with the same, leaving an outlet for the surface water between every sleeper.

From the manner of packing, all contact of the ballast with the earth of which the bank is composed, would be saved, and for keeping the Way up, a very small quantity only would be required. The ease with which such a style of permanent way would be maintained, and economy consequent thereon, is so apparent, as to need no further remark.

It is further clear that if we dispense with ballast we should not require the extra width of bank given to keep the ballast from spreading on the slopes, and 12 feet at formation level would I believe be found ample. This would also enable us to reduce the width of bridges.

In designing the fish-plate, care has been taken to increase the strength of the joint, and by a simple arrangement it will be seen that not only the bearing power of a sleeper at the joint is utilized, but also the transverse strength, the object in view being if possible to prevent, what is invariably the case on every line of railway on which I have travelled, viz., the blow or shock which is felt at every joint; which not only necessitates the exertion of a much greater power by the locomotive, than would be otherwise necessary, but involves more frequent lifting of the Way. This arrangement is shown in the plan, and in "linking-in" the clips on the lower part of the fish-plates should first be dropped into the square holes in the joint sleepers, and the whole slipped on the rail last laid; the next rail should then be pushed in, giving due allowance for expansion. It is obvious that the screwing up of the fish-plate bolts in combination with the wedge shape of the flange of the rail, will cause a powerful leverage to be exerted towards drawing the parts composing the joint very firmly together.

To prevent the rails from getting out of a straight line from the passage of trains, a cross plate or tie should be fixed immediately under the rail inside every joint sleeper. This is shown in section *(a)*, and might be joined to the sides of the sleeper by the end being bent to a right angle, or by a piece of angle iron, as the manufacturer might think best, with a

couple of rivets on each side. This would also materially increase the strength of the joint.

A statement is here given to show the comparative cost of the parts which are different from those in permanent way in common use, taking for this purpose that used on the Oudh and Rohilcund Railway, N. W. of Lucknow, the gauge being 5′ 6″. The fish-plate would cost about the same in both cases, and is not included.

Oudh and Rohilcund Railway.

Description.	Weight.	Cost in Lucknow.		
	lbs.	RS.	A.	P.
2 Pot sleepers, Livesay's patent, ...	160	6	10	0
2 Keys for above, ...	10	0	6	8
1 Tie-bar, ...	24	1	6	8
4 Cushions, ...	..	0	3	0
2 Cotters, ...	2	0	3	0
Totals, ...	196	8	13	4

Proposed Plan.

One wrought-iron sleeper with bolt, lbs. 140, probable cost, Rs. 8-12-0

The simplicity resulting from the great decrease in the number of parts is obvious.

In the plan, the fish-plate is shown extending beyond the sleeper, and with four bolts. It is possible that with the joint sleeper 12 inches broad, and the fish-plate the same in length, two bolts would be sufficient.

A style of Permanent Way with the rail bearing directly in a wrought-iron sleeper is in use on the Oudh and Rohilcund Railway below Lucknow, but it is very difficult to lay, owing to the method of fixing the rails on the sleepers, and has other disadvantages, which it is hoped the plan now proposed will obviate.

W. B.

No. LII.

BEAMS "FIXED" AND "SUPPORTED."

By Capt. Allan Cunningham, R.E., *Honorary Fellow of King's College, London.*

There is a remarkable discrepancy in statement of *the relative strengths* of a beam under transverse strain in the two cases of its being

(1). Firmly fixed at both ends.

(2). Simply supported at both ends.

The ratios given in different authors are either 3 : 2, 2 : 1, or 3 : 1. By some authorities, the difference is said to be wholly a difference between theory and experiment. If this were really the sole difference, it would probably follow that if the experiments were trustworthy, the theoretical results must have been founded on false premisses, and most practical men would be inclined to accept the results of experiment.

This is, however, by no means the case. The results obtained by experimentalists differ from each other, and those obtained by theorists differ also from each other. The present paper is *an attempt* to explain the cause of these discrepancies, which are so great as to be almost a disgrace to the profession.

The statement of results in the various authorities may be classed as follows:—

(1). Results derived directly from experiment.

(2). Results obtained theoretically from certain simple laws (of resistance of materials) previously established as very approximately true by experiment.

(3). Simple statements of actual results, without any evidence. These may be roughly styled results

(1) of experimentalists (*See* Table I).

(2) of theorists (*See* Table II).

(3) of copyists (*See* Table III).

The two former are obviously the only ones of real value as originals, the latter may be held however to represent the opinion of the profession.

It will be well to define the terms "strength" and "fixed," as great part of the discrepancies probably depend on different meanings being attached to these words. By "Strength" is meant one of two things—

(1). "Ultimate Strength" which is measured by the "Breaking Load."

(2). "Working Strength" which is measured by the "Working Load" (*i.e.*, greatest safe load).

By "fixed" is meant that the beam is supported and also firmly fixed *in direction* at both ends, *i. e.*, so that its neutral axis shall remain unaltered in position by the action of the load. The character of "fixing" requires particular attention: even so great an authority as Prof. Robison advances a demonstration (*v. infra*, Table III.) in which the beam is imperfectly fixed.

The relative strengths in question are stated generally for three distinct distributions of load:—

Case I. Load concentrated at middle of the beam.

Case II. Load uniformly distributed along the beam.

Case III. Load concentrated at any point in the beam.

The author has consulted* every work in the Central Library, Roorkee, which seemed likely to have any bearing on the subject, and has arranged the statements of the various authorities into three Tables I., II., III.—showing clearly the nature of the evidence (when recorded) on which each original author has based his statement, and has also recorded *his own opinion* on the character of the theoretical demonstrations given.

Discussion of the Experimental Evidence.

It is stated on high authority (Telford, P. Barlow, Tredgold) that the discrepancies are discrepancies between experiment and theory. This can however be the case only in Case I., when the beam is loaded in the

* It should be understood that the author has actually *consulted* every work from which he quotes, except those whose titles are in italics (of which there are no copies in the Roorkee Library).

middle, as *the experiments* (*see* Table I.) seem to have been made *in this case only*, so that all the authorities are alike theorists as regards Cases II. and III.

The most important of the experimentalists is undoubtedly P. Barlow, who distinctly declares *his opinion* that the experiments of Mariotte and Muschenbroek were not on a scale suited to determine the question, and that his own were conducted with great care on purpose to settle the discrepancy between the assigned ratios (of 3 : 2 and 2 : 1).

It is particularly to be noticed that the *experimental* ratio 3 : 2 is in every instance determined *from the Breaking Weight* of wooden battens of *uniform rectangular section* loaded *only at the middle.*

It is to be regretted that Prof. Robison who supports the ratio 2 : 1, which he obtained theoretically did not detail the experiments which he made to test his theory: they *appear* to have been experiments on deflection.

Discussion of Theoretical Demonstrations.

These may be classed under two heads.

(1). Demonstrations from Breaking Weights.

(2). Demonstrations from stresses within elastic limit.

Class 1. The author considers the whole of the demonstrations of the first class (from the authors quoted) unsound: the greater number depend upon several *unproved assertions* (the proof of the truth of which would be very difficult), and can therefore only be held as attempts at a popular demonstration, amounting in fact only to a *probability* of the truth of the result given. These the author has styled "hypothetical demonstrations."

The demonstration given by Prof. Robison the author considers as sound in itself, but inapplicable inasmuch as the beam which he considers is decidedly only imperfectly fixed over its supports,* as the neutral axis is permitted to take up a slope.

The unsatisfactory character of the demonstrations of this class may be seen from the discrepant results.

Class 2.—The results obtained from the more recent of these demonstrations (from stresses within elastic limits) have at any rate the merit of being consistent with one another with two important exceptions.

(1). By P. Barlow. (2). By the Rev. H. Mosely.

* His beam is laid continuous over 4 supports, and fixed at the two *outer*: he considers the central portion as a beam *fixed* at both ends!

P. Barlow's demonstration.—This is vitiated by the error (pointed out by the writer in Paper XLIV. of "Professional Papers on Indian Engineering," Second Series) made by Barlow in his Deflexion formulæ, viz., that the Deflexions in a cantilever and in a beam supported at the ends, loaded at middle, and *under the same load* are as $1 : \frac{1}{32}$. This error (the correct ratio is $1 : \frac{1}{16}$) is corrected in the 1867 edition of his "Strength of Materials:" the admission of this error of course destroys the *proof* of the ratio 3 : 2, and in fact reproduces the very ratio 2 : 1 of which P. Barlow is the principal antagonist.

But there are grave objections to the whole argument, as to which it is perhaps sufficient to note that the *supposed demonstration* has been omitted from the 1867 edition, which is perhaps sufficient proof that the later editors have felt these objections.

H. Mosely's demonstration.—The ratio 3 : 1 given is really the ratio of the longitudinal stresses at *centres* of the respective beams: this author has omitted to notice that in fixed beams (uniformly loaded) the greatest stress is at the abutments and is twice that at the centre. Introducing this modification Mosely's result becomes 3 : 2, *agreeing* with the other authorities of this Class in Case II.

Other demonstrations.—The whole of the demonstrations of this Class (except P. Barlow's) are obtained as the natural consequences of the following simple laws established *by experiment* as true for beams *only slightly deflected*, and *under stresses not exceeding the elastic limit*, viz.:—

(1). The longitudinal strain (*i. e.*, elongation or contraction) along any originally horizontal layer is proportional to the distance of that layer from a certain line, *i. e.*, the strain throughout a cross-section is *uniformly varying*.

(2). Stress varies as strain.

(3). The elongations and contractions of a bar under the same load when stretching and crushing respectively, are equal in amount.

The results must necessarily be true *within the limits prescribed* (viz. deflexion slight, and elastic limit not exceeded), *if these premisses are true*, but it will be absurd to infer that these results are even approximations beyond those limits, *i. e.*, *no inference* can be drawn as to ratios for *Breaking Weights.*

This method of demonstration, viz., from a consideration of the "elastic curve," or curve assumed by the neutral axis of the beam, appears

(to the author) to be the only safe method of treatment in the case of a beam which is both supported and fixed.

Remarks on Statement of Copyists.

These books are merely compilation of facts, but are important as showing the opinion of the profession. The compilers have not been sufficiently careful in invariably stating the "conditions" to which their ratios were applicable.

On the whole they bear out the author's opinion that in Case I., the ratio 3 : 2 is applicable to ultimate strength and the ratio 2 : 1 is applicable to working strength. It is remarkable that the modern compilers quoted are unanimous in giving the ratios as 3 : 2 in Case II, with the exceptions of Molesworth's and Nyström's Pocket-books.

Conclusions.

Case I.—It will have been noticed that the ratio 3 : 2 is for this case dependent chiefly on *Experiments on the Breaking Weights* of beams, and that of 2 : 1 chiefly on *Theoretical demonstrations* from Stresses *within elastic limits* (demonstrations from Breaking Weights being in the author's opinion unsound).

The authors conceives that the explanation of the *seeming* discrepancy probably lies in the fact that the ratios indicated are

(1) of Ultimate Strengths, by the experimentalists (viz., 3 : 2),
(2) of Working Strengths, by the theorists (viz., 2 : 1),

and are very likely both correct *under the conditions intended.* As to the comparative utility of these two ratios, the author believes that the general opinion of the profession now is that large beams should always be designed from the safe limit of stress—intensity of the material, not from the ultimate strength of the material.

Case II.—No *experiments* recorded (among the books accessible). The only sound demonstrations show the ratio of Working Strengths to be as 3 : 2.

Case III.—No experiments recorded, and no demonstrations discovered (among the books accessible). The author has calculated the ratio of Working Strengths according to the principles indicated by him, and finds it to be (not 3 : 2 as *stated* by some authorities) that of

"Clear Length of Beam : Greater Segment".

TABLE II. (*Continued.*)—Relative Strength of uniform straight horizontal beams when fixed and when supported at both ends.

(*From Theoretical Writers.*)

Class.	Title.	Author.	Date.	Case 1. Load at middle.		Case 2. Uniform load.		Case 3. Load anywhere.		Character of Demonstrations.
				Ratio.	Demonstration.	Ratio	Demonstration.	Ratio.	Demonstration	
Class (2).	Essay on Strength and Stress of Timber.	P. Barlow.	1826	3 : 2	From deflection					Hypothetical.
	Treatise on Strength of Timber, &c.	P. Barlow.	1845	3 : 2	ditto.					Hypothetical.
	Mechanical Principles of Engineering and Architecture.	Rev. H. Mosely.	1843			3 · 1 shd. be 3 : 2	Within elastic limit.			From consideration of "elastic curve" assumed by neutral axis under strains within elastic limit. These demonstrations are sound.
	Manual of Applied Mechanics.	W. J. M. Rankine.	1864	2 : 1	Within elastic limit.	3 : 2	ditto.			
	Course de Mécanique Appliquée de l'Ecole des Ponts et Chaussées.	M. Bresse.	1866	2 : 1	ditto.	3 : 2	ditto.			
	Theory of Strains.	B. B. Stoney.	1866			3 : 2	ditto.			
	Manual of Civil Engineering.	W. J. M. Rankine.	1870	2 : 1	ditto.	3 : 2	ditto.			
	Chatham Course of Civil Engineering.	Lt.-Col. Wray, R. E.	1870	2 : 1	ditto.	3 : 2	ditto.			
	Professional Papers on Indian Engineering [Second Series], No LVII.	Capt. A. Cunningham, R.E.	1872					Length : Greater Segment.	Within elastic limit.	

TABLE III.—Relative strength of uniform straight horizontal beams when fixed, and when supported at both ends.

(*From Copyists, no authorities given.*)

Title.	Author.	Date.	Case 1. Load at middle.		Case 2. Load uniform.		Case 3 Load anywhere.	
			Ratio.	Conditions.	Ratio.	Conditions.	Ratio	Conditions.
Memorandum book.	T. Telford.	1838	3 : 2 2 : 1	Not stated.				
Aide Mémoire de Mécanique.	A. Morin.	1845	2 : 1	Breaking weight.	2 : 1	Breaking weight.	2 : 1	Breaking weight.
Aide Mémoire de Mécanique Pratique	A. Morin.	1847	2 : 1	Working stress.	2 : 1	Working stress.		
Practical Mathematics.	A. Bell, Edinburgh.	1847	3 : 2	Breaking weight.	3 : 2	Breaking weight		
Encyclopædia of Civil Engineering.	E. Cresy.	1847	3 : 2	Breaking weight.	3 : 2	Breaking weight.		
Encyclopædia of Architecture.	P. Nicholson.		3 : 2	Not stated.	3 : 2	Not stated.		
Cyclopædia.	*Rees.*		3 : 2	?				
Builder's Guide.	G. D. Dempsey.	1851	3 : 2	Breaking weight.	3 : 2	Breaking weight.		
English Cyclopædia. Div. Arts and Sciences.	C. Knight.	1860	3 : 2	Breaking weight.				
Overseer's Pocket-book.	J. Hurst.	1868			3 : 2	Breaking weight		
Engineers' and Mechanics' Pocket-book.	Haswell.	1868	3 : 2	Breaking weight.	3 : 2	Breaking weight.	3 : 2	Breaking weight.
Engineers' Pocket-book.	Adcock.	1869	3 : 2	Not stated.	3 : 2	Breaking weight.		
Engineer and Architects' Pocket-book.	?	1869	2 : 1	Working stress.		Misprinted.		
Railway Construction.	Haskoll.	?	3 : 2	Breaking weight.	3 : 2	Breaking weight		
Instruction in Military Engineering, Chatham.	Various.	1870	3 : 2	Working stress.	3 : 2	Working stress.		
Useful Rules and Tables.	W. J. M. Rankine.	1870	2 : 1	Working stress.	3 : 2	Working stress.		
Pocket-book of Engineering Formulæ.	G. L. Molesworth.	1871			2 : 1	Breaking weight		
Elementary Principles of Carpentry.	T. Tredgold Ed. Hurst	1871	3 : 2	Breaking weight	3 : 2	Breaking weight		
Scantlings of Timbers for Roofs.	Ensign P. Keay.	1872	3 : 2	Breaking weight	3 : 2	Breaking weight.	3 : 2	Breaking weight
Pocket-book of Mechanics and Engineering.	J. W. Nyström, Philadelphia.	1872	2 : 1	Working load.	2 : 1	Working load.	1 : 1	Working load.

No. LIII.

FOURACRES' DEEP-WELL EXCAVATORS.

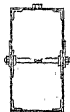
[Vide *Plates* Nos. XLVI. and XLVII.]

Invented and Patented by Mr. C. Fouracres, C.E.

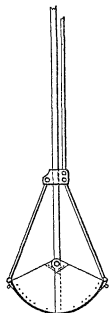
Before describing the new Deep-well Excavators in use on the Soane Anicut, and with the view of making this article complete, and rendering the working of the new machine intelligble to any readers who may not be acquainted with Mr. Fouracres' original invention, it is necessary to reproduce in an abridged form the description of the latter.

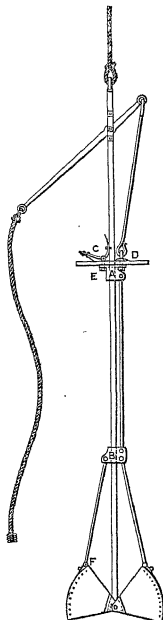
Fouracres' Well Excavator.—The accompanying drawing will make the construction and action of the Excavator clear with very few words of explanation; it consists of—

1*st.*—A spear of 1 inch square iron, 12 feet long, with shackle at the top to sling it by, and a cross-head at bottom.

2*nd.*—Two segmental scoops, hinged on the ends of the cross-head, and forming when closed (the edge of one slipping just within the other), a bucket of rather more than the third of a cylinder. Materials, sheet-iron and angle-iron for corners.

3*rd.*—Two iron collars A, B, sliding loosely on the spear, and connected at a fixed distance asunder, by a second side spear. To the lower collar are attached two hinged rods, F, to open and shut the scoops. To the upper collar, a small wooden platform, ED, is fixed, on which two men can stand whose weight will force down the instrument; or, in working below water, an iron weight can be substituted.

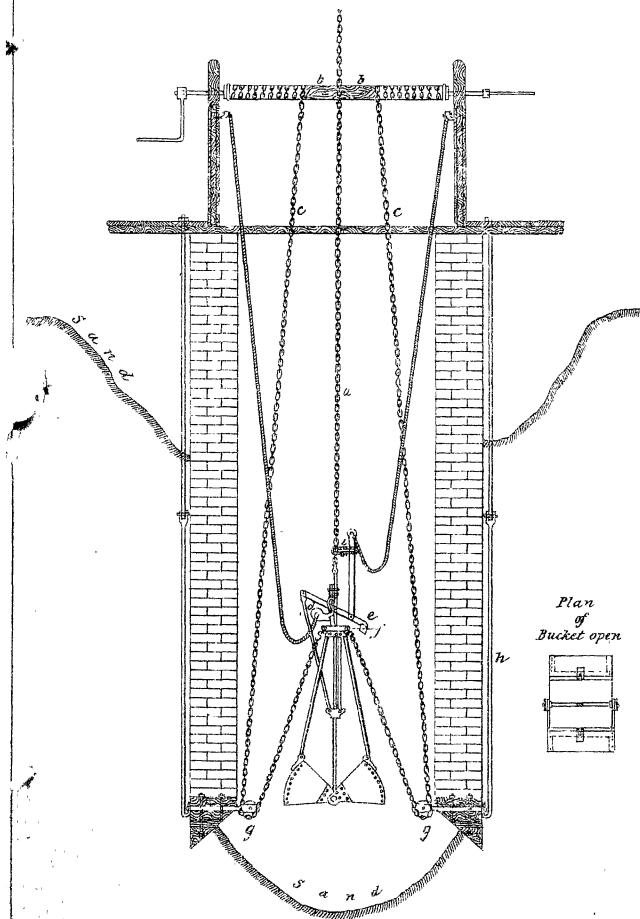
4th.—A lever hinged on the top of the spear to open the jaws of the scoop when over the discharge platform.

5th.—There are also two stops on the spear, and a spring clasp, C, to keep the jaws open while the scoop is being lowered.

The action is very simple. The machine is slung over the well or block by tackle and pulleys worked by a windlass, from any convenient form of staging; it is lowered, with the jaws in the open position, till it rests on the bottom; the two attendants step on the platform, and one with his foot releases the spring clasp; the windlass men at once wind up, but the weight of the men keeps the scoop from rising till the jaws have closed and it is full of sand; then all rise together; the two men step off on the sides of the well, and, as the full bucket rises to the level, they sway it over a wooden platform at the side, and pull smartly at the lever; the jaws open, and the catch holds them; so the sand falls out on the platform; the machine swings back, and is immediately lowered again, while the sand is shovelled or run away. This can be repeated at the rate of one lift per minute, lifting $1\frac{1}{4}$ to $1\frac{1}{2}$ cubic feet each time.

Deep-Well Excavator.—The action of the Excavator is in every respect similar to that of Fouracres' ordinary Excavator for small wells with this exception, that the process of closing the scoops of the Excavator is performed by two chains and a windlass, instead of by actual pressure by men's weight. The Excavator is lowered into the well, in the position shown in the drawing (*Plate* XLVI.) by the chain *a*,

the end of which is attached to a windlass in any convenient position : as the men lower the chain *a*, those at the windlass *b* wind up the chains *c* which become loose as the Excavator descends; when the Excavator reaches the bottom of the well, the catch *d* is released by means of the rope attached to it, and the scoops are closed by tightening up the chains *c*, which draws down the collar *f*, and so shuts the scoops upon the sand; when the Excavator has taken its load, the men at the windlass attached to the chain *a*, wind it up, and those at the windlass *b* unwind their chain, so that the Excavator is free to rise; when the machine reaches the top of the well it is swayed over the side, and the load released by opening the scoops with the lever *e*, which is hinged to render the machine more handy; when lowered into the well a small line *i* keeps the lever in position to prevent it fouling the side of the well.

The pulleys marked *g* through which the chain *c* runs, are put on to the well when the curb is first laid; the tie-rods outside, marked *h*, keep the pulleys in their places, while the well is being sunk and also tie the well together, to prevent the lower part falling in; they also keep the windlass *b* on the top of the well firmly in its place; when the well is sunk to the full depth, the outer rods are driven down clear of the hook; the pulley can then with very little trouble be extricated from the curb, for it only fits loosely into wood; the stirrup rods can then be drawn.

Self-Closing Deep-Well Excavator.—The Excavator is lowered into the well in the position shown by the dark-lined portion of the drawing, *Plate* XLVII. with the exception that the diagonal arms marked *b* are kept up in the position shown by the dotted lines, until the scoop of the Excavator takes the ground; when the scoop is resting on the ground, the arms (*b*) are lowered by means of the rope (*c*), until they are in the position shown by the dark-lined portion, when the Excavator is thus fixed as it were at the bottom of the well, for it is evident that the collar *a*, (which is firmly rivetted to the main rod of the Excavator,) is completely prevented from moving by the compression of the diagonal rods *b* upon it, the catch marked *d* is liberated by pulling the rope attached to it; when this is done the men at the windlass commence to wind up the main chain, which, being passed round the pulley *e*, and fastened to the collar *a*, draws down the collar *i*, and so presses the scoops of the Excavator into the ground; at the same time the cross head *f*, attached to the main chain rises with it, and as it rises it lifts the ring and chain *g*; the length of this chain is so

FOURACRE'S PATENT DEEP-WELL EXCAVATOR.
(In use on the Soane Anicut)
b
b
c
c
a
e
h
Sand
Sand
g
g
Plan
of
Bucket open
Scale 4 feet = 1 inch

adjusted, that at the same time as the jaws are closed, the tension of the chain *g* draws away the diagonals *b* from the side of the well, and when this is done the whole machine is free to rise with the load.

When the Excavator is lifted to the top of the well it is swayed over the side, and a chain attached to the scaffolding, which has been previously adjusted to the correct length, is hooked into the hook *h*; the men at the windlass then lower away, and as the chain attached to the hook becomes tightened, the weight of the Excavator causes the scoops to open and discharge their load, and at the same time the machine is re-set ready for lowering into the well.

C. F.

No. LIV.

MEMORANDUM ON SOME EXAMPLES OF WALLS AND ARCH BUILDINGS IN CEMENT CONCRETE.

[Vide *Plate* No. XLVIII.]

By Lieut., H. C. Fox, R.E.

1. *Petroleum Store at Bristol.*—This building is an example of an attempt to carry the advantage possessed by concrete over other building materials, viz., saving in cost, to its utmost limit. The structure as is evident from the sketch, is somewhat of a *tour de force*, and its partial failure, though due in a great measure, to faulty and unscientific design, tends to show that in the use of concrete it is unwise to save money at the expense of the factor of safety.

(Referring to the sketch) the dimensions of walls and arches are as follows :—

Party walls (piers), 6″ thick.
Arches at springing, 5″ „
„ crown, 4″ „

Dimensions below floor level (in cement concrete) are not known.

Method of tracing abutment arches in end chambers not known ; but in these two instances, the sketch gives a fair idea of the architect's drawings. The concrete was made of Portland cement, of very good quality (a high test for resistance to crushing, and tearing apart being specified) mixed with five times its bulk of furnace "clinkers," and I believe a small quantity of sand. The "clinkers" were used with a view to obtaining a concrete of small weight, though the architect could give no satisfactory reason for his wish to obtain this quality, and as the clinkers, varied a good deal in porousness and resistance to crushing (some being vitrified, while others were little stronger or harder than common coal

nders) they were very unsuitable for use in concrete, which as in this case had to stand a severe and irregular strain. I was told that great care was taken in mixing, laying, and ramming the concrete, the work being constantly supervised by a foreman of works appointed by the architect. The contractor also was a well known and trustworthy man.

A glance at the sketch will show that the structure of cement concrete was most unscientifically and unfairly loaded, and as might have been expected, when the load was put on, one of the end arches burst outwards at the haunch (D in sketch), and all the building on one side of the central passage (*see* plan) fell in; the party walls however, were not entirely thrown over, but broke at *a*, *a*, *a*, and the end walls stood. Moreover the corresponding range at the other side of central passage, when I saw it after the accident, showed no signs of failure, though it must have been subjected to a severe shake when the other range fell. The arches fell in very large pieces, but did not break in the floor. The concrete work had been completed two months when the failure took place.

I may add that the architect having attributed the failure to bad material having been used by the contractor, and a lawsuit threatening, the proprietor asked me to give him my opinion on the case. After inspecting the work, I was able to convince the architect, that he was to blame for the failure, and eventually he compromised the matter, bearing ⅔rd the expense of rebuilding.

I also suggested the following alterations in the design, which I believe will be carried out in rebuilding the fallen part, and applied as far as possible to the part which remained standing.

1. Concrete in new walls and arches to be made of broken hard stone, (each piece to be small enough to pass through a 2-inch ring), mixed with mortar (made of one cement, to one pit-sand) in quantity sufficient to a little more than fill the interstices between the stones. This quantity to be determined by experiment (one mortar to six stone will be about the proportion).

2. The concrete to be rammed till each stone touches the adjacent ones.

3. Iron tie-rods to be introduced in the arches, except the end ones.

4. The contour of the superstructure to be altered somewhat as shown on sketch in dotted lines.

With these alterations I think the structure will be safe, though as the foundation is notgood, the chambers should not be unequally loaded.

II. *Fortifications at Bermuda.*—The typical plan of a casemated bat-

tery given in the R.E. Professional Papers, Vol. XIX. (1871)., *Plate* VI., to face page 90, is almost co-incident with the design of Fort Cunningham, Bermuda, (a work of which I was in charge for three years). The principal differences are as follows :—

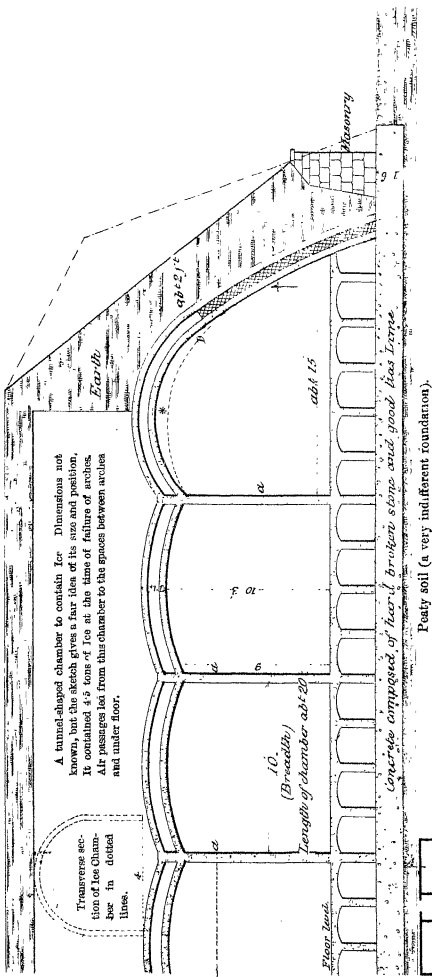
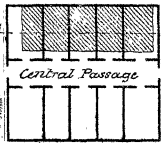
Ground level, ft. c. same as that of 'gun-floor,' the magazines being in an excavation. Span of arches 16′ 6″ instead of 18′ 9″. Dry ditch. Fort Cunningham, is on the top of a hill.

After about half the magazines had been built in masonry, the C.R.E. decided that the remainder of the work should be executed in cement concrete, and when I gave up charge of the work this had been done, with the exception of the arching of the superstructure.

The concrete was made of hard crystalline limestone, Portland cement, and oolitic limestone powder (used as sand), and as concrete for building purposes had not been used before at Bermuda, a great number of combinations were tried before a final proportion between above materials was arrived at. At first the hard stone was broken by hand, but eventually a "Blake's stone crusher," (for description, *see* Gillmore, on Limes, &c., page 243, *et seq.*), was obtained, and used with very satisfactory results. From the solid block, this machine produced broken stone (to go through a 2 inch ring), containing about 12 per cent. of coarse sand, and most of the work was built of concrete composed of nine parts broken stone, with its sand in it, to two parts cement mortar (one Portland cement to one soft stone sand).

This concrete was laid at the rate of 9″ per diem, and when finished, had a fine smooth surface, as good as if it had been rendered. Movable boards wedged out from uprights were used as moulds for the walling; and in arching, a ring of brick (with a few headers to bond with concrete above) was turned over the centres to form a soffit, and the remaining 2 feet of the arch formed in concrete. In one case an arch of 10 feet span, (about 2 feet rise) was built entirely of concrete, and the centering struck 8 days after the arch was complete. This was done as an experiment, and not the slightest settlement could be observed. In some cases no stone or other lintels were used over openings in the walls, and all the openings and shafts for shell and powder lifts, issuers, lamp boxes, &c., were formed in the concrete, by wooden moulds slightly greased.

The principal difficulty was found in forming exterior angles, which on plan are shown rounded. A variety of expedients were tried to overcome

PLATE XLVIII.
PETROLEUM STORE AT BRISTOL.
Scale 7½ feet = 1 inch.
Transverse section of Ice Chamber in dotted lines.
A tunnel-shaped chamber to contain Ice Dimensions not known, but the sketch gives a fair idea of its size and position. It contained 4·5 tons of Ice at the time of failure of arches. Air passages led from this chamber to the spaces between arches and under floor.
Earth
abt 2 ft
10.
(Breadth)
Length of chamber abt 20
10 3
abt 15
Floor level.
Masonry
Concrete composed of hard broken stone and good lias Lime
Peaty soil (a very indifferent foundation).
Central Passage
Small Plan.
Section above is on A B.
Failure shaded.
* Soffit as shown on Architects Plans. The height of crown of this arch was raised by the Architect at the request of the Foreman of works. This alteration probably had much to do with the failure.
† 4½" ribs of concrete, about 5 feet apart, connecting inner and outer arches at this place.

this difficulty, and the most successful in my opinion was that of building a quoin at each angle, either of 14 or 9 inch brick, stone, or best of all, in moulded concrete blocks. These quoins should be built in strong cement mortar, and if formed of blocks of stone or concrete, these may be dowelled with small wooden dowels. In ramming the concrete a considerable thrust is sometimes brought against these quoins, which must be strong enough to withstand it (*see* sketch). Besides ensuring the accuracy of the concrete work, these quoins improve its appearance when finished.

Sketch to show method of forming exterior angles.

The cost of this concrete at Bermuda was about $\frac{7}{10}$ths that of brickwork. Generally, however, the cost of concrete depends on so many contingencies, such as—

Cost of unskilled labor,
Carriage of materials,
Water supply, &c.,

that its cost, as compared with that of brickwork or masonry, will vary at every different locality.

I consider that Portland Cement is the only safe material of its kind, which can be used in building "pisé" concrete walls, but good *blocks* may be made of many other materials if sufficient time can be allowed for "setting." I have made good blocks with *pure* lime and sand;—puzzuolana (St. Vincent's), pounded brick, or ground cinders being mixed in certain proportions.

Some suspicion has been of late cast on the durability of Portland and other artificial cements. Being stationed at Harwich, Essex, where Portland cement has been manufactured for many years, and extensively used for building purposes, I observed some cases of old Portland cement rendering which presented a honey-combed (or 'shelly' as it is called in those parts) appearance, but I think this may have been caused by the proximity of the sea, and the consequent presence of muriatic acid in the atmosphere. I have never been able to observe or hear of any other cause for the above suspicion.

H. C. F.

No. LV.

WEBB'S SUB-AQUEOUS EXCAVATOR.

[Vide *Plate Nos.* XLIX. and L.]

Description of Webb's Patent Sub-Aqueous Excavator. BY E. W. STONEY, ESQ., *Resident Engineer, Madras Railway.*

THE excavator is a cylinder, from which about a fourth part is removed, to form horizontal and vertical cutting edges *a*, *b*, *Plates* XLIX. and L. It is formed of boiler plate rivetted to angle iron framing. On top are two iron catches C, D, which receive the wrought-iron bow E, this slides up and down the square guide bar F.

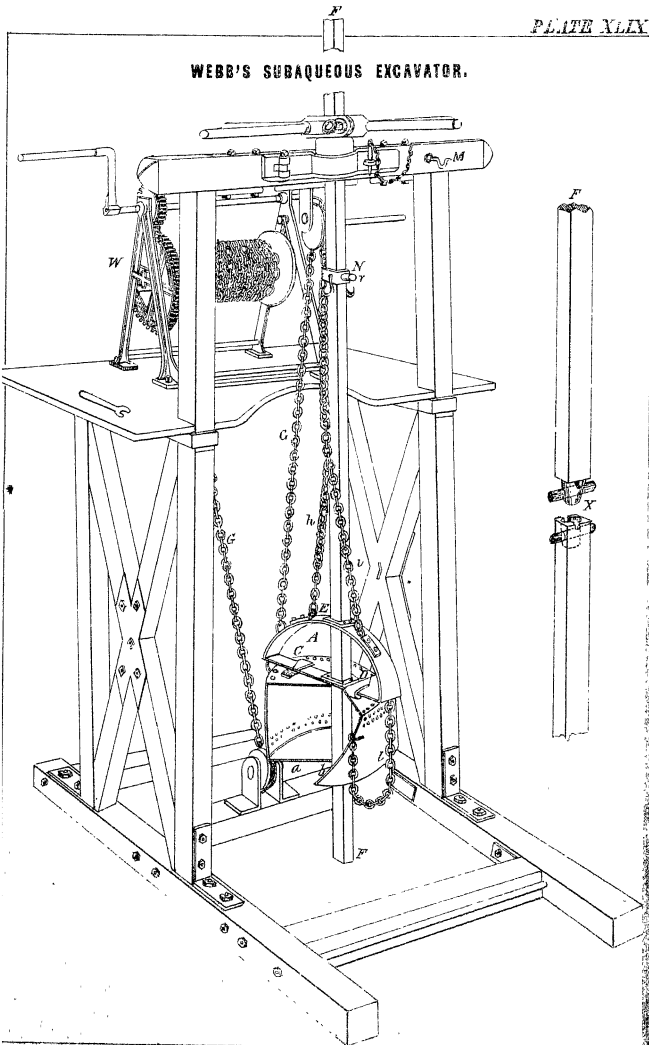
To the upper side of this bow the hoisting chain G, is attached by short pieces *h*, *i*, while underneath a pair of short chains *k*, *l* connect it with the excavator.

The square bar F, by means of which the excavator is turned and guided in its ascent and descent, together with its capstan, crab winch, and framing, all clearly shown in the drawings, complete the apparatus. The guide bar F is made in convenient lengths, connected by the joint X, and carries a sliding collar N, which can be clamped at any part of it, by means of pinching screw *r*.

On each side of this collar a hook is rivetted for the purpose of supporting the hoisting chains G, when disconnected.

The hoisting chain is provided with special links every six feet, which allow of its separation at them.

The mode of using the excavator is as follows:—The frame is placed as shown in *Plate* XLIX., over the cylinder or well to be sunk, and the bar F dropped to the bottom of it. The crab barrel is then thrown out of gear, which allows the excavator to descend by its own weight, being guided in its descent by the bar F, which passes through the bow E: as soon as it reaches the bottom of the well, the hoisting chain G is disconnected at ne of the links provided for the purpose, the upper part leading from

WEBB'S SUBAQUEOUS EXCAVATOR.

the winch being hooked to the frame at M, while the lower part which is connected with the excavator is hooked to the collar N: this allows the excavator to be turned without getting the chain G twisted round the bar; the men at the capstan then give a few turns from right to left, which fills the excavator; (5 turns are generally sufficient to do so). A quarter turn of the capstan in the opposite direction releases the bow E from the excavator, which remains embedded in the material being excavated; the chain G is now unhooked at N, M, and joined up as before, and the bow E drawn up by turning the winch W; as soon as it is raised to the extent of the chains *k*, *l*, it lifts the excavator, and at the same time tilts it as shown in *Plate* L, in which position it is drawn to the top and emptied into a truck provided for the purpose; or to save time, the full excavator may be removed, and an empty one hooked on to the chains *k*, *l*; so that when this comes up full, the former one will be ready to take its place, to be again lowered and filled.

The inventor states that the most useful sizes are 1 foot 6 inches diameter by 9 inches deep, and 2 feet diameter by 1 foot deep: (the former size being suited to hard material, such as stiff clay, &c., and the latter to softer stuff, as mud, sand, &c.): that this excavator will raise per day on an average, 60 cubic feet of hard material, such as stiff clay and laterite gravel, from a depth of 50 or 60 feet below water, *when worked exclusively by men*: that this rate may be increased to 180 cubic feet per day, if a steam crab or hoist be used; and that probably double these quantities of soft stuff would be raised. Six men are sufficient to work this machine.

The inventor further says, that the cost of the excavator complete with frame, crab, chains, &c., would be about Rs. 300, and a royalty of £50 per annum for the use of each machine will be charged.

The cost of a steam winch 4 horse power with boiler and steam fittings complete would be about Rs. 1,800. Assuming these data, the cost of working would be, as under:—

By Manual Labor.

	RS.	A.	P.
6 Men, at Rs. 0-6-0 per day,..	2	4	0
1 Mistry, at Rs., ...	1	0	0
Wear, depreciation of machinery, repairs at 25 per cent per annum on value, Rs. 300, ...	0	3	10
Royalty on patent, Rs. 500 per annum, ...	1	9	7
Cost per day, ... Total,	5	1	5

for 60 cubic feet excavated, or a rate of Rs. 0-1-4 per cubic foot = Rs. 2-4-0 per cubic yard.

By Steam Power.

		RS.	A.	P.
1 Engine driver, at Rs. 1 per day,	..	1	0	0
1 Stoker, at Rs. 0-8-0,	..	0	8	0
7 Men coolies, at Rs. 0-4-0,	..	1	12	0
$2\frac{1}{2}$ Cwt coal, at Rs. 30 a ton,	..	3	12	0
$\frac{3}{4}$ ℔ Oil,	..	0	2	0
25 Per cent on Rs. 2,100 for wear, depreciation, and repairs of machinery,	..	1	10	10
Royalty on patent,	..	1	9	7
Cost per day, ..	Total,	10	6	5

Quantity excavated 180 cubic feet, or a rate of Rs. 0-0-11 per cubic foot, or Rs. 1-8-9 a cubic yard.

If wood fuel be used, the cost would be for fuel $7\frac{1}{2}$ cwt., at Rs. 3 per ton = Rs. 1-2-6. This would reduce the cost of working to Rs. 7-12-11 a day = Rs. 0-0-8 per cubic foot, or Rs. 1-2-0 per cubic yard.

This excavator had a prolonged practical trial in sinking the Iron Cylinder foundations for the Kudlahoondy Bridge, Madras Railway. Twenty-six cylinders 6 feet diameter, were sunk by means of these excavators to depths of from 37 feet to 65 feet below the water level,

through 2 feet of mud.
" 10 " sand.
" 25 " blue clay.
" 15 " laterite gravel, very hard.
" 3 " decayed granite.

The above trial proves beyond doubt its practical value.

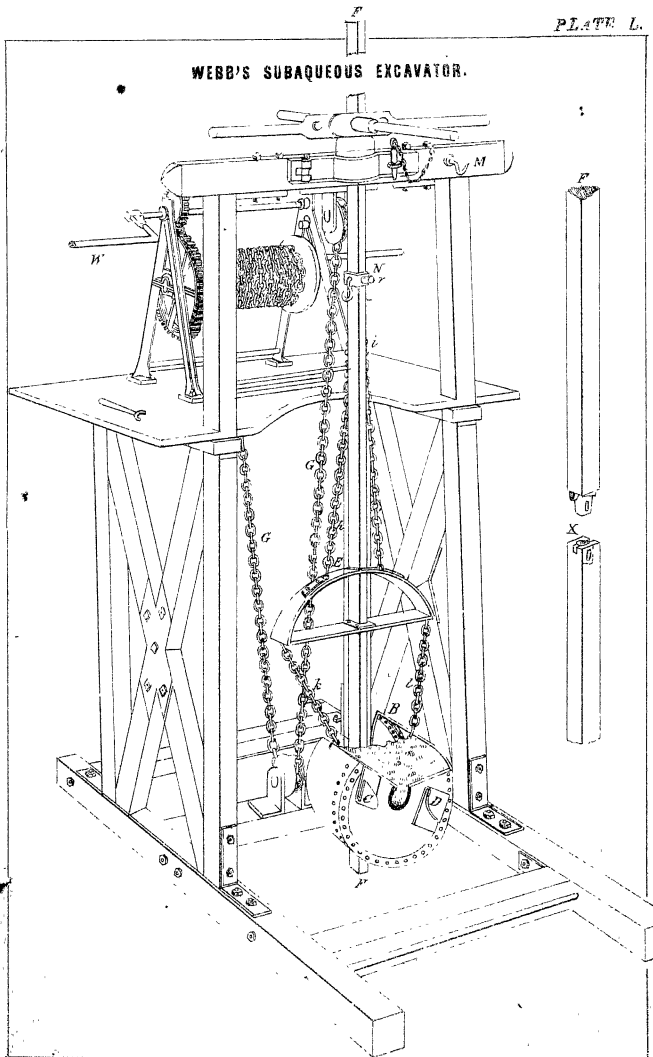
This excavator will, if tried in the N. W. Provinces, probably prove a formidable rival of the sand pump, and other excavators now in use.

Its chief merits appear to the writer to be its great strength and simplicity, which make it almost impossible to break or put out of order.

The simple manner in which it is used makes it peculiarly suited to the capacity of ordinary native workmen.

E. W. S.

PLATE L.

WEBB'S SUBAQUEOUS EXCAVATOR.

No. LVI.

EARTH CURRENTS AND AURORÆ BOREALES.

By J. J. Fahie, Esq., *Jask Station, Indo-European Telegraph Department.*

On the night of the* 4th-5th February last, I had the good fortune to witness a grand magneto-electric disturbance on four of the sections of the Persian Gulf telegraphs. It was accompanied by an Aurora Borealis, which must have been one of unusual splendour. I can hardly conceive that the luminous phenomenon which I witnessed was the actual Aurora, for, as these meteors have their sphere in the region of the clouds, they cannot be more than three or four miles high *at the pole*, and, therefore, it is quite impossible that I could have seen anything but a reflection at this low latitude ($25\frac{1}{2}°$ north.)

As seen from Jask station, it took the shape, roughly, of an elongated ellipsoid, of a reddish-pink color, resting on the northern horizon, with its smaller end stretched out towards the east. It continually varied as regards color, now brighter, now dull; but its position did not alter from its first appearance at 11 P. M. to 1-30 A. M. (Kurrachee time*) when I last saw it. The Auroræ, as usual, was preceded by a faint whitish glow in the west, which was noticed about an hour after sunset, and which, as the evening advanced, became more distinct, assuming, roughly, a pyramidal shape, with its base on the horizon. There was no moon, and the atmosphere was particularly clear, with a moderate breeze from the north.

The telegraph may be said to stand in the same relation to this class of phenomena, as the barometer does to atmospheric changes. A certain

* The time followed in this paper is Kurrachee time, which is about 45 minutes in advance of the true local time.

behaviour on the part of the former as surely indicates the prevalence of a "magnetic storm," as does that of the barometer the approach of an atmospheric one. To me the irregular and spontaneous working of the telegraph was, (if I may so speak) the harbinger of the Aurora, for hours before its reflection was visible, the wires told very plainly of its existence.

At 6-55 P. M. a permanent positive current was observed on the Jask-Gwadur cable. This was at first set down to some irregularity in the instrument at the distant station; but such was soon ascertained not to be the case. Presently a similar current but weaker was perceived on the land-line between the same stations, while at almost the same moment permanent negative currents took possession of the Jask-Bushire and Jask-Fao cables. It was now evident that "earth currents" were about, and in very strong force too, as appeared from the deflections of the galvanometer needles which form part of the working apparatus. After a few minutes the direction of the currents charged, the cable and land-line between Jask and Gwadur became charged with negative electricity, and the Jask-Bushire and Jask-Fao sections with positive. Thr throughout the evening, and at intervals of 2 to 5 and 10 minutes currents were constantly varying in direction and force. Soon afte appearance it was found very difficult to correspond with any distant stations; and from 8 P.M. to midnight, communication was entirely suspended except for a brief space at those particular times when the existing current was dying out, to give place to the succeeding one, which rapidly approached its maximum strength and in its turn receded.

Shortly after midnight, the earth currents entirely forsook the land-line, or at all events became so feeble, as not to be perceived on the ordinary instruments. They disappeared from the cable circuits about the same time, but at 12-30 on the morning of the 5th, they again set in on the Jask-Gwadur cable, and continued at long intervals (during which communication was satisfactory) up to 8 A.M.; when they finally vanished, ending with a negative current which had uninterrupted possession of the line from 7-30 to 7-50 A.M. The Jask-Bushire and Jask-Fao lines were free from midnight to 2 A.M.; at which time strong negative currents set in for about one hour. From 3 A.M., no further disturbance was reported on the Jask-Fao cable; but the Jask-Bushire line was again, and for the last time, visited by negative currents which remained off and on

from 6 to 8 A.M. The regular weekly tests of the cables taken late on the forenoon of the 5th, showed that even then the earth currents although too feeble to interfere with the working, had not entirely vanished.

It was observable between 7 P.M. and midnight, that the land line and cable to the eastward of us were always charged with the same kind of electricity, while the Jask-Bushire and Jask-Fao lines were as invariaby charged with the opposite kind; it was also noticed that the current, were reversed in all the circuits at the same time, the one pair changing from positive to negative, at the same time that the other pair changed from negative to positive, and *vice versa*. Those on the Jask-Fao section, which is the longest of the cables, 655 knots, at one time arrived at such a high tension, that whenever the connection between the line and earth was interrupted, a strong spark was emitted.

Some experiments were made to determine the quantitative strength or intensity of the currents. The highest intensity measured was that on the Jask-Bushire line, where it was equal to that of 57 Minotti cells. At one period of the evening, it must have far exceeded this number on the Jask-Fao cable, for I was unable to obtain from the largest battery power available, (80 Minotti cells,) and through the same resistance as the cable, as strong a spark as that noted above:—

The following are a few of the observations taken at intervals during the evening :—

Jask-Fao and Jask-Bushire Sections.

Time.	Resistance in circuit.	Earth current deflection.	Name of current.	Calculated strength of Earth current.
8-50 P.M.	5,198 units	59°	+	39 Minotti cells.
9-20 „	14,198 „	33°	+	41 „ „
10 „	13,508 „	45°	+	57 „ „
11-10 „	4,330 „	150°	+	25 „ „
11-15 „	„ „	85°	+	14 „ „
11-20 „	„ „	8°	—	1·33 „ „

The first three deflections were observed on a tangent galvanometer, the remainder with Sir. W. Thomson's delicate mirror instrument.

When describing the auroral reflection, I Stated that it was constantly varying in depth of color. Now this might be caused by clouds passing before the aurora, or by some other changes in the reflecting medium. I will nevertheless hazard a conjecture that these variations corresponded with the different phases of the aurora itself, and also that they coincided with the alternations of the earth currents. In conclusion of this part of my subject, I have only to add that the Jask-Gwadur cable and land-line lie nearly east and west, and the Jask-Bushire and Jask-Fao lines north-west.

All electrical disturbances, such as I have now described, or such as are produced by thunder-storms, by polarisation of the earth plates to which the ends of a line are connected, by differences in the state of the weather and atmosphere or inequalities in the altitude at distant points of a line, &c., are technically called "Earth currents." From one cause or another these currents are always present in telegraph wires, particularly submarine cables. Happily, however, they are not often possessed of sufficient strength to interrupt communication,* and generally they are so feeble as only to be measured by the aid of testing instruments. In England it has been found that lines which pursue a N.E, and S.W, course are most subject to disturbance, while on the continent those lying E. and W. are generally more affected. Again it has been remarked in England that lines N. W, and S. E, are seldom disturbed, and then only to a slight extent, while my experience shows me that, as regards the degree of disturbance at all events, this rule does not hold good for the Persian Gulf. But the fact is Philosophers have not yet been able to trace any laws concerning either their direction or strength. Sometimes they are most powerful N. and S., and at other times E. and W., at one time they flow steadily in one direction for long periods, at another they change about in a most capricious manner from positive to negative in quick succession.

When they are accompanied by an Aurora borealis, and by certain abnormal perturbations, of the magnetic needle, they constitute, together with these two phenomena, what Humboldt has been the first to describe "as a Magnetic storm."

During the last four years there were probably not more than half a dozen instances of the cables in the Persian Gulf being seriously and for any considerable time disturbed by earth currents. I myself can only recollect four cases, in one of which (13-14 May 1869) the currents changed on the Jask-Gwadur section from 19 Daniell cells positive to 14·5 negative in about 10 minutes, and on the Jask-Bushire from 21 negative to 5 positive within the same time.

Many people regard the Aurora and earth currents in the light of cause and effect; but this is altogether a fallacy, for, to whatever influence they must be attributed, it is certain they are both the products of one and the same agency. Whether this be a purely electrical one, as suggested by De la Rive, or magneto-electric as advanced by Humbolt, is as yet undecided, although the balance of belief inclines greatly to the latter hypothesis.

De la Rive considers the Aurora as due to the discharges which take place in polar regions between the positive electricity of the upper atmosphere and the negative electricity of the earth and the stratum of air in connection with it; the earth currents being caused by differences in the electrical state of the earth consequent on these discharges. If this be a correct explanation the Aurora can hardly be said to be a distinct phenomenon from lighting. It seems to me that being identical in the manner of their formation, &c., the one should be as universal as the other.

Late experiments however have failed to sustain the electrical theory, inasmuch as during the finest Auroræ the most sensitive electroscopes have not been affected, while the magnetic needle has always undergone very sensible, and at times, considerable, variations.

It is now generally admitted that all these abnormal variations of the needle and, indirectly, Auroræ and earth currents are the effects of a disturbance of terrestrial magnetism, a disturbance which is connected in some as yet unexplained way with the sun's spots. Humboldt's theory is that the disturbance of the earth's magnetism (begot by the solar agency) induces a like disturbance of the electrical equilibrium, and that it is the electricities of the earth and of the atmosphere so disturbed, which, in their efforts to re-establish a balance, produce earth currents on the one hand and Auroræ on the other.

In what manner the number and magnitude of the spots on the sun operate in producing magnetic storms has not been clearly proved: up to the present philosophers have only succeeded in establishing the fact that these spots and the magnetic and electric perturbations of our earth increase side by side by annual increments and attain their maxima at the same time every ten years or thereabouts. This remarkable coincidence indicates that if the sun or his spots be not the first and great cause of magnetic storms there is at all events reason to suspect a close connection between them.

If we accept this theory I think it is easy to explain why Auroræ al-

ways appear at the magnetic poles: thus we know the intensity of the earth's magnetism is there greatest: at these points therefore the solar influence exerts itself in greatest force and produces the greatest amount of magnetic disturbance. This in its turn induces the greatest electrical disturbance at and around the poles and thus gives rise to those magnificent displays.

The question of earth currents as forming part of the important subject of magnetic storms has for many years past engaged a great share of attention at most (if not all) of the observatories in Europe. Special wires have been erected for the Greenwich observatory with sensitive galvanometers in circuit, the variations of whose magnetic needles are daily recorded in all their *minutiæ* by the aid of photography. I am not aware whether the Colaba Institution is similarly provided. If not, no time should be lost in properly representing the matter to Government. Valuable opportunities are every day wasted: for if it be true that temperature by expanding the atmosphere has something to do in disturbing the earth's electrical equilibrium, in other words, in producing earth currents, it is obviously in such situations as Bombay, Calcutta, and Madras, that this conjecture can be best subjected to direct test At all events much information would be acquired, which in time would probably tend to the elucidation of the true cause of these phenomena and of the laws that govern them.

No. LVII.

[Vide *Plates* Nos. LI. and LII.]

USEFUL RULES AND TABLES FOR TIMBERING OF FLAT ROOFS.

By Major W. H. Mackesy, B.G.C., F.A.S., *Assoc. Inst.* C.E., *Executive Engineer.*

I had at first intended bringing out a set of tables for the scantlings of beams, rafters, &c., of various kinds of timber under such loads as occur in Indian practice, but as I found that the work would have taken up more time than I could spare for the purpose the intention was given up. The following rules and tables will be found of great use in calculating the scantlings of beams, as in every case the paper work is reduced to simple multiplication and division. I have used the tables myself for a considerable time, and the constants for deflection and strength for many years. There are possibly errors in the tables, although every precaution for securing accuracy has been adopted, and if any such are noticed, I shall be glad if they are pointed out. The constants have been calculated for sál, teak, deodar and fir, a few blank lines are left in each table which will allow of constants for other timbers being inserted in manuscript if desired. The value of E_d I have taken for deodar is 2,500; that adopted in the Roorkee Treatise is 3,565. This is I am convinced much too large.

Experiments carried on at Murree* (in I think 1856), gave E_d from 2,200 to 3,200; observations of existing flat roofs seems to show that 2,500 is about a suitable value to adopt. Rankine gives E_t for cedar of Lebanon (supposed to be the same tree as the deodar) at 486,000, which reduced to the Roorkee $E_d = 1,125$.

* Report on flexion and fracture of deodar and fir-woods, Robertson and Henderson.

All experiments to determine E_d, have been (at least in the case of Indian woods), carried out with small pieces; and it is very desirable that its value should be determined from experiments on timbers of large size. This might be done without expense by observation of the actual deflection of the timbers of flat roofs. It would be a simple matter to score a straight line at each side of one or more beams of each roof before erection, marking with a small nail or screw or otherwise the point over the centre of each wall plate, and the centre of the beam. The deflection could then be measured with sufficient accuracy after erection, by stretching a fine line over the extreme screws. It is also a question whether a greater deflection than one-fortieth of an inch per foot of span might not be allowed for flat roofs. This in the case of a 24 feet span roof would be $\frac{6}{10}$ of an inch, an almost imperceptible amount. Observations on the actual deflections of the timbers of existing flat roofs which are in a satisfactory condition would be valuable. The question is important in an economical point of view.

Rules and Tables.

From the well known equations for the strength and central deflection of horizontal rectangular wooden beams supported at each end, and uniformly loaded, viz. :—

$$\delta = \frac{5}{32} \cdot \frac{Wl^3}{bd^3 E_t}, \quad \ldots\ldots \quad (1).$$

$$W = \frac{4bd^2 . f}{3l}, \quad \ldots\ldots \quad (2).$$

where

δ = central deflection in inches.

W = uniformly distributed load in pounds.

l, b, d = length between supports, breadth and depth all in inches.

E_t = co-efficient of elasticity $= \frac{1728 E_d}{4}$, (E_d, being the co-efficient used in the Roorkee Treatise).

f = the co-efficient of transverse strength $= 18\ p$ (p being the co-efficient used in the Roorkee Treatise).

s = the factor of safety (taken = 10).

we readily obtain by putting.

$\delta = \frac{l}{480}$, w = load in pounds per running foot of span, L = length

in feet, r = ratio of depth to breadth $= d \div b$; C_b C_d c_b c_d constants given in the following tables:—

$$b \text{ or } d = (C_b, \text{ or } C_d) \times \sqrt[4]{w L^3} \ \ldots\ldots\ldots \ (3) \text{ from } (1).$$

$$b \text{ or } d = (c_b \text{ or } c_d) \times \sqrt[3]{w L^2} \ \ldots\ldots\ldots \ (4) \text{ from } (2).$$

$$\text{In (3) } (C_b \text{ or } C_d) = \left(\sqrt[4]{\frac{1}{r^3}} \text{ or } \sqrt[4]{r}\right) \times \sqrt[4]{\frac{25}{E_d}} \text{ and}$$

$$\text{in (4) } (c_b \text{ or } c_d) = \left(\sqrt[3]{\frac{1}{r^2}} \text{ or } \sqrt[3]{r}\right) \times \sqrt[3]{\frac{s}{2p}}$$

Thus both the deflection and strength formulæ are each broken up into three factors.

C or c, depending on the kind of timber, and the ratio of depth to breadth selected in any particular case.

$\sqrt[4]{L^3}$ or $\sqrt[3]{L^2}$, depending on the span.

$\frac{1}{\sqrt[4]{w}}$ or $\frac{1}{\sqrt[3]{w}}$,, ,, load per running foot of the beam.

Values of these factors for each formula will be found in the following Tables for the loads, spans, and ratios of depth to breadth of ordinary occurrence.

If it is desired to limit the central deflection of a proposed beam to $\frac{1}{40}$th inch per foot of span

$$(b \text{ or } d) = (C_b \text{ or } C_d) \times \sqrt[4]{L^3} \div \frac{1}{\sqrt[4]{w}} \text{ from (3).}$$

and if the beam is to be strong enough to be at the point of fracture under 10 times the proposed load

$$(b \text{ or } d) = (c_b \text{ or } c_d) \times \sqrt[3]{L^2} \div \frac{1}{\sqrt[3]{w}} \text{ from (4).}$$

In permanent structures it is usual and desirable to fix the scantlings of the beams and rafters with reference both to stiffness and strength, making use of both formulæ, and adopting the larger result. The following diagram shows at a glance whether in any particular case the deflection or strength formula would give the larger scantling, thus saving the designer the trouble of making the double calculation. The diagram exhibits the span for each unit load at which either formula gives the same scantling, and for a greater span the deflection formula gives the larger scantling.

The following formula has been used in constructing the diagrams.

Since the required span for any unit load is that for which d from (3) $=$ d from (4); we have—

$$\sqrt[4]{r} \times \sqrt[4]{\frac{25}{E_d}} \times \sqrt[4]{w L^3} = \sqrt[3]{r} \times \sqrt[3]{\frac{10}{2p}} \times \sqrt[3]{w L^2}$$

$$\text{Whence } L = \frac{E^3}{p^4} \times \frac{r\,w}{25} \text{ .... (5).}$$

In the case of a cylindrical beam $r = \frac{16}{3\pi} = 1{\cdot}698$. The value of $\frac{E^3}{p^4}$ is to be calculated for the kind of timber required, then find the value of $\frac{r\,w}{25}$ for each value of r in ordinary use, putting $w = 1{,}000$; and lastly set off the several values of L at 1,000 lbs. on the diagram, drawing straight lines to 0 lbs. The ordinate at each intermediate load will give the required span for that load.

A series of examples of the use of the diagram and tables will be found in note A.

The formulæ (3) and (4) are made applicable to the case of angle beams or other beams similarly loaded, by taking w = the average load per running foot on the beam, and proceeding as if w thus found were a uniform unit load. (A proof will be found in Note B; the rule is strictly speaking approximate, but is near enough to the truth for all practical purposes).

In designing a flat roof, the spacing of the main beams is often fixed by the position of the openings, size of the available timber, &c.; when this is not the case, it is worth while to adopt the spacing which involves the least possible expenditure of timber. This point is investigated in Note C, with the following results.

When the roof covering is to be carried by rafters or bullies of certain fixed dimensions, it is self-evident that the most economical arrangement is to space the beams at the distance which the rafters can safely span, which call S. If the beams are to be placed nearer together than this distance, the waste of timber may be found as follows:—

put A = content of one beam per running foot of a roof for spacing S.
,, B = ,, ,, ,, ,, ,, S_1.

$$\text{then } B = A\sqrt{\frac{S}{S_1}} \text{ .... (6).}$$

Example—A flat roof is to be carried by bullies which may have a bearing up to 10 feet, and it is proposed to place the main beams 5 feet apart, what waste will be caused by this arrangement?

$$\text{Put } A = \text{unity}, \; B = \sqrt{\frac{10}{5}} = 1{\cdot}414,$$

or 41 per cent. more timber will be used in the main beams if spaced at 5 feet, than if a 10 foot spacing were adopted.

When as is usually the case in permanent buildings, the exact scantling of the rafters is not fixed beforehand.

Calling the most economical spacing, S in feet
,, the span or bearing of the main beams, L ,,
,, the ratio of depth to breadth fixed for the rafters r
,, ,, ,, main beams R,

we have $S = {\cdot}577 \; L^{\frac{3}{4}} \times \left(\frac{r}{R}\right)^{\frac{1}{4}}$, ... (7) A.

derived from the deflection formula.

If the cost per cubic foot of the beams is .... V rupees.
,, ,, ,, ,, rafter ,, ... v ,,

The most economical spacing as regards cost is

$S = {\cdot}577 \; L^{\frac{3}{4}} \times \left(\frac{r}{R}\right)^{\frac{1}{4}} \times \left(\frac{V}{v}\right)^{\frac{1}{2}}$, ... (7) B.

Table showing the most economical spacing for the main beams of flat roofs (or bearing of the burgahs) for all kinds of timber (no minimum section being fixed for the burgahs).

From formula (7) A.

Values of R and r.	Span in feet.										
	15	16	17	18	19	20	21	22	23	24	25
$R = r$, ...	4 40	4 62	4·83	5 04	5·24	5 46	5 66	5 87	6·05	6·25	6 44
$R = \frac{3}{2}, r = \frac{1}{1}$, ...	3·96	4·17	4 35	4 55	4 74	4·93	5·11	5 27	5·47	5·63	5·82
$R = \frac{2}{1}, r = \frac{1}{1}$, ...	3·69	3 88	4 05	4 23	4 41	4·57	4 76	4 93	5 10	5 25	5·42
$R = \frac{2}{1}, r = \frac{3}{2}$, ...	4 08	4 30	4 48	4·68	4 87	5 07	5 26	5 45	5 63	5·83	5·99

It will be observed that the above spacings are independent of the unit load on the beams.

A certain minimum section of rafter is however always adopted in practice, usually 3′ × 3″ in ordinary flat roofs. The maximum bearing

which should be given to such rafters spaced 1 foot from centre to centre under a permanent load of 125 pounds per superficial foot is as follows:—

	feet.		feet span.	
Teak, ...	4·62	And this spacing should be adopted up to	18·30	(beyond these spans formula (7) applies).
Sál,..	5·04		20·28	
Fir, ...	4·70		18·60	
Deodar, ...	4·02		15·20	

The value of R for the beam being taken at $3 \div 2$.

Formulæ Nos. (10) and (11) for ascertaining the waste of timber caused by any departure from the above rule, will be found at the end of note C, they are however rather complicated, and are omitted here.

In roofs of small span such as verandahs, it is sometimes a question whether the timbering should be of rafters alone, stretching from wall to wall, or of rafters carried on beams. An investigation of the point will be found in note D, formulæ Nos. (12) and (13). The following results are obtained therefrom. If the large rafters and beams have the depth = once and a half the breadth, and if the small rafters are square, with a fixed scantling of 3″ × 3″.

For sál timber, beams and rafters are more economical beyond a 9′ 10″ span.

For deodar, " " " 7′ 7″

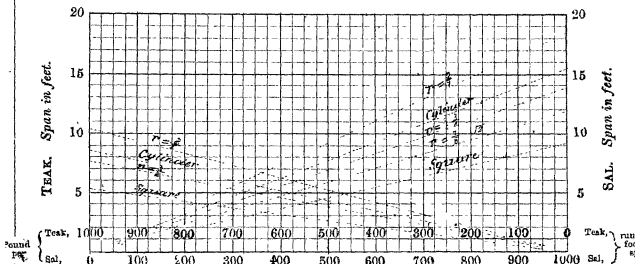
TIMBERING OF FLAT ROOFS.

DIAGRAMS.

Showing span for each unit load at which deflection and strength formulæ give the same scantling (*see* text).

Teak, $\frac{E_d{}^3}{p^4} = \frac{(3840)^3}{(814)^4} = 1289$

$\frac{\cdot 1289 \times 1000}{25} = 5\cdot 158$

Sál, $\frac{E_d{}^3}{p^4} = \frac{(4963)^3}{(880)^4} = \cdot 204$

$\frac{\cdot 204 \times 1000}{25} = 9\cdot 154$

TEAK. *Span in feet.* 20, 15, 10, 5

SAL. *Span in feet.* 20, 15, 10, 5

$r = \frac{2}{3}$ Cylinder $r = \frac{1}{2}$ Square

$r = \frac{2}{3}$ Cylinder $r = \frac{1}{2}$ Square

Pound per { Teak, 1000 900 800 700 600 500 400 300 200 100 0 ; Sal, 0 100 200 300 400 500 600 700 800 900 1000 } Teak, Sal, run foot

Fir, $\frac{E_d{}^3}{p^4} = \frac{(4000)^3}{(600)^4} = \cdot 494$

$\frac{\cdot 494 \times 1000}{25} = 19\ 75$

Deodar, $\frac{E_p{}^3}{p^4} = \frac{(2500)^3}{(500)^4} = \cdot 25$

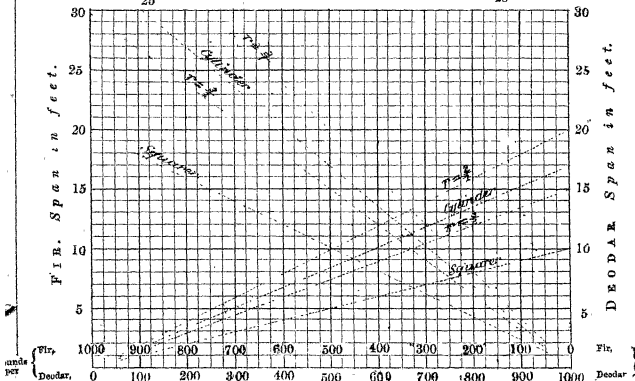
$\frac{\cdot 25 \times 1000}{25} = 10$

FIR. *Span in feet.* 30, 25, 20, 15, 10, 5

DEODAR. *Span in feet.* 30, 25, 20, 15, 10, 5

$r = \frac{2}{3}$ Cylinder $r = \frac{1}{2}$ Square

$r = \frac{2}{3}$ Cylinder $r = \frac{1}{2}$ Square

Pounds per { Fir, 1000 900 800 700 600 500 400 300 200 100 0 ; Deodar, 0 100 200 300 400 500 600 700 800 900 1000 } Fir, Deodar

Directions for use.

If the intersection of the load and span lines falls below the diagonal corresponding to *r*, use the *strength* formulæ: if above, use the *deflection* formulæ. Halve unit loads greater than 1000 lbs., and double the span cut by *r*.

The diagrams are constructed only for a deflection of [illegible]

Table of constants for use in "Deflection" formula (Load equally distributed). Deflection $= \frac{1}{40}$-inch per foot of span.

Formula is $(b'' \text{ or } d'') = (C_b \text{ or } C_d) \times \sqrt[4]{w L^3} = (C_b \text{ or } C_d) \times \sqrt[4]{L^3} \div \sqrt[4]{\frac{1}{w}}$.

Table of Auxiliary numbers for obtaining constants.

Table of constants for use in "Strength" formula. Factor of safety = 10; (load equally distributed).

Formula is $(b'' \text{ or } d'') = (c_b \text{ or } c_d) \times \sqrt[3]{w L^2} = (c_b \text{ or } c_d) \times \sqrt[3]{L^2} \div \sqrt[3]{\frac{1}{w}}$.

Table of Auxiliary numbers for obtaining constants.

$\sqrt[3]{\frac{1}{r^2}}$ (for obtaining c_b), ..	1·000	·862	·826	·799	·763	·711	·688	·676	·658	·630				Diameter, $\sqrt[3]{\frac{16}{3\pi}} = 1·193$
$\sqrt[3]{r}$ (for obtaining c_d), ..	1·000	1·077	1·101	1·118	1·145	1·185	1·205	1·216	1·233	1 260				Circumference, $\sqrt[3]{\frac{16\pi^2}{3}} = 3·748$

Timber.	Value of p.	Side of sq beam. $c = \sqrt[3]{\frac{10}{2\cdot 7}}$	Values of $r = \frac{d}{b}$ = depth ÷ breadth.											Cylinder.
			$\frac{5}{4}$	$\frac{4}{3}$	$\frac{7}{5}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{7}{4}$	$\frac{9}{5}$	$\frac{15}{8}$	$\frac{2}{1}$			
			Constants for b and d corresponding to above values of r.											
Sál, ... c_b	880	·1784	·154	·147	·143	·136	·127	·123	·121	·117	·113			Diameter, ... ·213
c_d			·194	·197	·200	·204	·211	·215	·217	·220	[illegible]			

															Girth, ...	·671
Teak, ... c_b	814	·1831	·158	·151	·147	·140	·130	·126	·124	·121	·115				Diameter, ...	·219
c_d			·197	·202	·205	·210	·217	·221	·222	·126	·231				Girth, ...	·688
Deodar, ... c_b	500	·2154	·186	·177	·172	·164	·153	·148	·145	·142	·135				Diameter, ...	·257
c_d			·223	·237	·240	·246	·255	·259	·261	·265	·271				Girth, ...	·808
Fir, ... c_b	600	·2027	·175	·167	·162	·155	·144	·139	·137	·133	·128				Diameter, ...	·242
c_d			·218	·223	·227	·232	·240	·244	·246	·250	·256				Girth, ...	·762

Table of values of $\sqrt[3]{L^2}$ and $\sqrt[3]{\frac{1}{w}}$ for use in the formula $(b \text{ or } d) = (c_b \text{ or } c_d) \times \sqrt[3]{L^2} \div \sqrt[3]{\frac{1}{w}}$.

Span in feet L.	Values of $\sqrt[3]{L^2}$.
4	2·520
5	2·924
6	3·302
7	3·659
8	4·000
9	4·327
10	4·642
11	4·946
12	5·242
13	5·529
14	5·809
15	6·082
16	6·349
17	6·612
18	6·868
19	7·120
20	7·368
21	7·612
22	7·851
23	8·088
24	8·320
25	8·550

Load in pounds per running foot of beam = w.	Values of $\sqrt[3]{\frac{1}{w}}$.
50	·272
75	·237
100	·216
125	·200
150	·188
200	·171
250	·159
300	·149
350	·142
400	·136
400	·131
550	·122
550	·216
600	·119
650	·115
700	·112
750	·110
800	·108
850	·106
900	·104
950	·102
1000	·100
1100	·097
1200	·094
1300	·091
1400	·089
1500	·087
1600	·085
1700	·084
1800	·082
1900	·081
2000	·079
2200	·077
2400	·075
2600	·073
2800	·071
3000	·069

The constants for b'' or d'' for each value of r are found by taking the product of $\sqrt{\frac{10}{2p}}$ (or the constant for side of a square beam), and the number corresponding to $\sqrt[3]{\frac{1}{r^2}}$ or $\sqrt[3]{r}$ in the table of auxiliary numbers. Thus for deodar the $\frac{5}{3}$ constants are obtained as follows:— c_b = ·2154 × ·676 = ·145, and c_d = ·2154 × 1·216 = ·261.

NOTE.—If it is desired to use a factor of safety s other than 10, enter the table with $w_1 = \frac{w \times S}{10}$. If the scantling for a central load = W be required, enter the table with $w = \frac{2\,W}{L}$. For an angle beam or hip rafter, enter the table with $w = \frac{W}{L}$, W being the total load on the beam.

USE OF THE TABLES AND DIAGRAMS.

Note A.

Example 1.—A sál beam is to carry a uniformly distributed load of 700 lbs. per running foot, span to be 21 feet, b to d as 1 to $\sqrt{2}$ = (as nearly as possible as 5 is to 7).

First, on referring to the "sál" diagram, the $\frac{7}{5}$ diagonal cuts the 700 lbs. load line at $8\frac{1}{4}$ feet, and therefore the (deflection) formula gives the larger scantling,—then

$$d = \frac{\cdot 29 \times 9\cdot 81}{\cdot 194} = 14\cdot 8 \text{ and } b = \frac{5 \times 14\cdot 8}{7} = 10\cdot 5$$

these results may be obtained at sight by the common slide rule, thus

A	9·81	depth = 14·8	breadth = 10·5
B	·194	·290	·207

the use of the slide rule is strongly recommended with these tables as giving a sufficiently accurate result without the trouble of paper calculations.

A deodar beam 15 feet span under a central load of 4,500 lbs. $d \div b = 2$. The diagram is of no use in this case, $w = \frac{8 \times 4500}{5 \times 15} = 480$ lbs. for use in the deflection formula, and $w = \frac{2 \times 4500}{15} = 600$ lbs. for use in the strength formula.

Then for stiffness

$$d = \frac{\cdot 376 \times 7\cdot 625}{\cdot 214} = 13\cdot 4 \text{ and } b = 6\cdot 7,$$

and for strength

$$d = \frac{\cdot 271 \times 6\cdot 082}{\cdot 119} = 13\cdot 9 \text{ and } b = 6\cdot 95,$$

To prove the correctness of the above results,

$$\delta = \frac{4500 \times (15)^3}{6\cdot 7 \times (13\cdot 4)^3 \times 2500} = \cdot 376 = \text{approximately } \frac{15}{40} = \cdot 375$$

$$\text{and } W = \frac{bd^2 \times 500}{LS} = 4500$$

$$\text{whence } S = \frac{4500 \times 15}{6\cdot 95 \times (13\cdot 9)^2 \times 500} = \frac{13500}{1343} = 10\cdot 04.$$

A fir kurrie 12 feet long, loaded with 150 lbs. per foot, is to have a central deflection of $\frac{1}{30}$ inch per foot of span, required the scantling. $w = \frac{30 \times 150}{40} = 112$ lbs. $(r = \frac{3}{2})$, $b = \frac{\cdot 207 \times 6\cdot 45}{\cdot 308} = 4\cdot 35$, and $d = 6\cdot 5$.

Proof of the above:—

$$\delta = \frac{5}{8} \cdot \frac{150 \times (12)^4}{4{\cdot}35 \times (6{\cdot}5)^4 \times 4000} = \text{nearly } {\cdot}105,$$

the required deflection being $\frac{12}{30} = {\cdot}4$.

A deodar bullie for a mud roof of 10 feet span is loaded with 100 lbs. per running foot, required its girth, factor of safety being fixed at $7\frac{1}{2}$.

$$w_1 = \frac{100 \times 7{\cdot}5}{10} = 75$$

$$g = \frac{{\cdot}808 \times 4{\cdot}612}{{\cdot}237} = 16 \text{ inches.}$$

The same, factor of safety being 10,

$$g = \frac{{\cdot}808 \times 4{\cdot}642}{{\cdot}216} = 17{\cdot}5 \text{ inches.}$$

The same, deflection not to exceed $\frac{1}{40}$th per foot,

$$g = \frac{1{\cdot}135 \times 5{\cdot}623}{{\cdot}316} = 20{\cdot}3 \text{ inches.}$$

Note.—Bullies usually taper, but if placed head and butt, the strength of each pair will be greater than if perfect cylinders of girth equal to the central girth of the bullies were placed side by side.

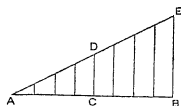
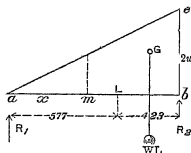
For if d be the diameter of each bullie at the centre, and d_1 be the difference between the diameters of the ends, then at any point distant x from the centre, the diameter $= d \pm \frac{d_1 x}{l} = \frac{d\,l \pm d_1 x}{l}$, and the sum of the moments of rupture of the pair of bullies at any point x varies as $2d^3 + \frac{6\,.\,d\,.\,d_1^2\,.\,x^2}{l^2}$, but the sum of the moments of rupture of the pair of cylinders at any point varies as $2d^3$, and hence the strength of the pair of bullies is always the greater. It is also manifest that the *stiffness* of the pair of bullies will be greater.

In flat mud roofs or whenever bullies are used as rafters, the bullies should therefore always be placed head and but.

An angle beam for a 12 foot verandah carries a flat roof 120 lbs. weight per superficial foot, on burgahs, to be of sál, $r = \frac{3}{2}$ (the verandahs meet at right angles). The load from the central pair of burgahs evidently equals $6 \times 120 = 720$ lbs., and the space between the burgahs from centre to centre along the beam $= 1{\cdot}42$ feet, hence the average load per running foot of angle beam $= \frac{720}{1{\cdot}42} = 510$ lbs., and the bearing of the beam $= 17$ feet. Reference to the diagram shows that the "deflection" formula should be used,

$$\therefore d = \frac{{\cdot}294 \times 8{\cdot}372}{{\cdot}210} = 11{\cdot}7, \text{ and } b = 9{\cdot}85.$$

Note B.

Let AB be an angle beam, DC the central jack rafter, the load from which on the beam $= w_1$ let $n =$ the number of jack rafters, then the total load on the beam $= nw_1 = \text{W}$, and the average load per running foot of beam $= \frac{\text{W}}{\text{L}} = w$. It is clear that the load on AB and the manner of its distribution may be represented by the right-angled triangle abe, area $= w\text{L}$, $ab = \text{AB} = \text{L}$, $be = 2w$. Since be is vertical, the vertical line through the centre of gravity of the whole load cuts ab at a point distant $\frac{\text{L}}{3}$ from b, and hence the re-action at $a = \text{R}_1 = \frac{w\text{L}}{3}$ and re-action at $b = \text{R}_2 = \frac{2w\text{L}}{3}$. The bending moment M at any point m, distant x from a taken as the origin

$$= \text{R}_1 x - \frac{wx^3}{\text{L}} = \frac{w\text{L}x}{3} - \frac{wx^3}{3\text{L}} = \text{A}x - \text{B}x^3 = u.$$

to find the value of x which makes u a maximum

$$\frac{du}{dx} = \text{A} - 3\text{B}x^2 = 0, \therefore x^2 = \frac{\text{A}}{3\text{B}}$$

$$\therefore x = \frac{\text{L}}{\sqrt{3}} = \cdot 577\text{L}$$

makes the bending moment a maximum, and the value of the maximum bending moment $=$

$$\text{M}_0 = \frac{2w\text{L}^2}{3^{\frac{3}{2}}} = \frac{w\text{L}^2 \times 1 \cdot 0264}{8} \text{..................................(8).}$$

The maximum bending moment of a horizontal beam under a uniform load per unit $= w$ is known to be $\frac{w\text{L}^2}{8}$, and therefore an angle beam may be treated as an uniformly loaded beam under its average unit load without sensible error in ordinary cases.

Again taking a as the origin of co-ordinates, and ab as the axis of x, it is known that

$$\text{EI}\frac{d^2y}{dx^2} = \frac{wx^3}{3\text{L}} - \frac{w\text{L}x}{3} = \frac{w}{3\text{L}}(x^3 - \text{L}^2x).$$

Integrating twice,

$$\mathrm{EI}\frac{dy}{dx} = \frac{w}{3\mathrm{L}}\left(\frac{x^4}{4} - \frac{\mathrm{L}^2x^2}{2} + \mathrm{C}_1\right)$$

$$\mathrm{EI}y = \frac{w}{3\mathrm{L}}\left(\frac{x^5}{20} - \frac{\mathrm{L}^2x^3}{6} + \mathrm{C}_1x + \mathrm{C}_2\right)$$

$\mathrm{C}_2 = 0$, for when $x = 0$, $y = 0$,

again when $x = \mathrm{L}$, $y = 0$

$$\therefore 0 = \frac{\mathrm{L}^4}{20} - \frac{\mathrm{L}^4}{6} + \mathrm{C}_1 \quad \therefore \mathrm{C}_1 = \frac{7\,\mathrm{L}^4}{60}$$

$$\therefore \mathrm{EI}y = \frac{w}{3\mathrm{L}}\left(\frac{x^5}{20} - \frac{\mathrm{L}^2x^3}{6} + \frac{7\,\mathrm{L}^4x}{60}\right) \ldots\ldots\ldots\ldots(\mathrm{A}).$$

which is the equation to the deflection curve. To find the value of x which makes y a maximum

$$u = \frac{x^5}{20} - \frac{\mathrm{L}^2x^3}{6} + \frac{7\,\mathrm{L}^4x}{60}$$

$$\frac{du}{dx} = \frac{x^4}{4} - \frac{\mathrm{L}^2x^2}{2} + \frac{7\,\mathrm{L}^4}{60} = 0, \therefore x = \pm\,\mathrm{L}\sqrt{1 \pm \sqrt{\tfrac{8}{15}}}$$

$$= \mathrm{L} \times \cdot 519328$$

putting $\mathrm{A} = \sqrt{1 - \sqrt{\tfrac{8}{15}}}$, $x = \mathrm{A\,L}$

substituting in (A)

$$\mathrm{EI}y = \frac{w}{3\mathrm{L}}\left(\frac{\mathrm{A}^5\mathrm{L}^5}{20} - \frac{\mathrm{A}^3\mathrm{L}^5}{6} + \frac{7\,\mathrm{AL}^5}{60}\right) = w\mathrm{L}^4 \times \frac{2\cdot 347}{180}$$

$$y = \frac{w\mathrm{L}^4}{\mathrm{E}bd^3} \times \frac{12 \times 2\cdot 347981}{180} = \frac{w\mathrm{L}^4}{\mathrm{E}bd^3} \times \frac{5\cdot 009}{32} \ldots\ldots\ldots\ldots\ldots\ldots(9).$$

The maximum deflection of a similar beam under a uniform unit load $= w$ is known to be $= \frac{w\,\mathrm{L}^4}{\mathrm{E}bd^3} \cdot \frac{5}{32}$

which differs but slightly from (9).

Note C.

From the formula for deflection, we have—

$$b = \sqrt[4]{\frac{1}{r^3}} \times \sqrt[4]{\frac{25}{\mathrm{E_d}}} \times \sqrt[4]{w_1\,\mathrm{L}^3}$$

$$d = \sqrt[4]{r} \times \sqrt[4]{r\frac{25}{\mathrm{E_d}}} \times \sqrt[4]{w_1\,\mathrm{L}^3}$$

$\therefore$ content of a beam in terms of its length and load

$$= bd\,\mathrm{L} = \frac{1}{r^{\frac{1}{2}}} \times \left(\frac{25}{\mathrm{E_d}}\right)^{\frac{1}{2}} \times w_1^{\frac{1}{2}} \times \mathrm{L}^{\frac{5}{2}}$$

$$\text{or } \frac{c\,w_1^{\frac{1}{2}}\,\mathrm{L}^{\frac{5}{2}}}{r^{\frac{1}{2}}} \left(\text{writing } c = \left(\frac{25}{\mathrm{E_d}}\right)^{\frac{1}{2}}\right) \ldots\ldots\ldots\ldots\ldots(\mathrm{B}).$$

If s = the space between two adjoining beams, or the unsupported length of a burgah, and if the burgahs be uniformly loaded with w pounds per running foot, the distance from centre to centre of each burgah being one foot, the foot load on each beam from a pair of burgahs, one at each side $= w_1 = w\,s$.

If first the timber in the burgahs be not taken into consideration.

$$A = \left\{ \begin{array}{c} \text{Content of a beam per running} \\ \text{foot of roof for spacing} = S \end{array} \right\} = \frac{cS^{\frac{1}{2}}\,w^{\frac{1}{2}}\,L^{\frac{5}{2}}}{S \times r^{\frac{1}{2}}} \text{ from ...... (B).}$$

$$B = \quad " \quad " \quad = S_1 = \frac{cS_1^{\frac{1}{2}}\,w^{\frac{1}{2}}\,L^{\frac{5}{2}}}{S_1 \times r^{\frac{1}{2}}}$$

$$A : B :: \sqrt{S_1} : \sqrt{S}, \text{ and } B = A\sqrt{\frac{S}{S_1}} \text{ ....(6).}$$

Second, taking the burgahs into consideration,—as before, unit load on each burgah $= w$, and from (B) we have content of one burgah $= \frac{cw^{\frac{1}{2}}\,S^{\frac{5}{2}}}{r^{\frac{1}{2}}}$ and as the number of burgahs in each bay $= L$, if we assume the length of the roof to be infinite, we have contents per running foot of roof,

$$\text{For the burgahs} = \frac{cw^{\frac{1}{2}}\,S^{\frac{5}{2}}\,L}{r^{\frac{1}{2}}\,S} = \frac{cw^{\frac{1}{2}}\,L}{r^{\frac{1}{2}}}.\,S^{\frac{3}{2}} = AS^{\frac{3}{2}}$$

For the content of a beam per running foot of roof, we have, since the unit load on a beam $= wS$, and writing R for $\frac{d}{b}$,

$$\frac{cw^{\frac{1}{2}}\,S^{\frac{1}{2}}\,L^{\frac{5}{2}}}{R^{\frac{1}{2}}\,S} = \frac{cw^{\frac{1}{2}}\,L^{\frac{5}{2}}}{R^{\frac{1}{2}}\,S^{\frac{1}{2}}} = BS^{-\frac{1}{2}}$$

and therefore the total quantity of timber per running foot

$$= AS^{\frac{3}{2}} + BS^{-\frac{1}{2}} = u$$

$$\frac{du}{dS} = \frac{3}{2}\,AS^{\frac{1}{2}} - \frac{1}{2}\,BS^{-\frac{3}{2}} = 0 \;\therefore\; S = \sqrt{\frac{B}{3\,A}}$$

gives a minimum value to u.

$$S^2 = \frac{cw^{\frac{1}{2}}\,L^{\frac{5}{2}}}{3\,R^{\frac{1}{2}}} \times \frac{r^{\frac{1}{2}}}{cw^{\frac{1}{2}}\,L} = L^{\frac{3}{2}} \times \frac{1}{3} \times \left(\frac{r}{R}\right)^{\frac{1}{2}}$$

$$S = L^{\frac{3}{4}} \times \cdot 577 \times \left(\frac{r}{R}\right)^{\frac{1}{4}} * \ldots\ldots\ldots\ldots (7)\ A.$$

A certain spacing having been assumed to ascertain the saving or excess caused by any deviation therefrom, call the content per running foot of roof corresponding to spacings S and S_1, respectively A and B, then we have—

$$\frac{cw^{\frac{1}{2}} L}{r^{\frac{1}{2}}} S^{\frac{3}{2}} + \frac{cw^{\frac{1}{2}} L^{\frac{5}{2}}}{R^{\frac{1}{2}}} S^{-\frac{1}{2}} = \frac{cw^{\frac{1}{2}} L}{S^{\frac{1}{2}}} \left(\frac{S^2}{r^{\frac{1}{2}}} + \frac{L^{\frac{3}{2}}}{R^{\frac{1}{2}}} \right) = A$$

$$B = \frac{cw^{\frac{1}{2}} L}{S_1^{\frac{1}{2}}} \left(\frac{S_1^2}{r^{\frac{1}{2}}} + \frac{L^{\frac{3}{2}}}{R} \right)$$

$$\text{whence } \frac{B}{A} = \frac{R^{\frac{1}{2}} S_1^2 + L^{\frac{3}{2}} r^{\frac{1}{2}}}{R^{\frac{1}{2}} S^2 + L^{\frac{3}{2}} r^{\frac{1}{2}}} \left(\frac{S}{S_1}\right)^{\frac{1}{2}} \quad \ldots\ldots\ldots\ldots (10).$$

if $R = r$, this becomes

$$\frac{B}{A} = \frac{S_1^2 + L^{\frac{3}{2}}}{S^2 + L^{\frac{3}{2}}} \left(\frac{S}{S_1}\right)^{\frac{1}{2}}, \ldots\ldots\ldots\ldots (11).$$

say for a 20 foot span, $S = 5$, and $S_1 = 7$.

$\frac{B}{A} = \frac{49 + 89}{25 + 89} + \cdot 85 = 1 \cdot 13$, or a waste to the amount of 13 per cent. would be caused by spacing the beams at 7 instead of 5 feet.

If S_1 be made 10

$\frac{B}{A} = \frac{100 + 89}{25 + 89} \times \cdot 71 = 1 \cdot 17$, the waste in this case would be 17 per cent.

NOTE D.

To find the span beyond which beams and burgahs should be used instead of kurries. The limitation caused by the desirability of using a minimum section of burgah must be taken into account, call this minimum section A, and spacing at which this section is stiff enough for the proposed load S.

* If the rate per cubic foot of the timber for the beams is greater than that for the burgahs, Call the rate per foot for the beams V, and the rate per foot for the burgahs v, then the formula for the most economical spacing as regards *cost* is

$$S = \cdot 577\, L^{\frac{3}{4}} \times \sqrt[4]{\frac{r}{R}} \times \sqrt{\frac{V}{v}} \quad \ldots\ldots\ldots\ldots (7)\ B.$$

Thus if the timber be sál, rate for large scantlings Rs. 4, and for small Rs 3.

$\sqrt{\frac{V}{v}} = \sqrt{\frac{4}{3}} = 1 \cdot 155$, and for a 24 foot span ($R = r$) the most economical spacing would be

$6 \cdot 25 \times 1 \cdot 155 = 7 \cdot 22$ feet

Then we have, x being the required span,

$AS x$ = content of the burgahs for one bay,

$\frac{c\, w^{\frac{1}{2}}\, S^{\frac{1}{2}}\, x^{\frac{5}{2}}}{R^{\frac{1}{2}}}$ = ,, ,, beam ,, ,,

$\frac{c w^{\frac{1}{2}}\, S^{\frac{1}{2}}\, x^{\frac{5}{2}} S}{r^{\frac{1}{2}}}$ = ,, ,, kurries with which the above might be replaced (spaced 1 foot from centre to centre.

$$\therefore\ AS x + \frac{c w^{\frac{1}{2}} S^{\frac{1}{2}} x^{\frac{5}{2}}}{R^{\frac{1}{2}}} = \frac{c w^{\frac{1}{2}} x^{\frac{5}{2}} S}{r^{\frac{1}{2}}}$$

$$\text{whence } x = \sqrt[3]{\frac{(E_d\ A^2\, S\, R\, r)}{25\, w\,.\,(S\,R + r - 2\sqrt{S\,R\,r})}} \ \ldots\ldots\ldots\ldots\ (12)\ A.$$

$$\text{or if } R = r\ \ x = \sqrt[3]{\frac{E_d\ A^2\, S\, R}{25\, w\, (S + 1 - \sqrt{S})}} \ \ldots\ldots\ldots\ldots\ (13)\ A.$$

If the cost per cubic foot of the timber in the beams = V,

and ,, ,, ,, ,, ,, kurries and burgahs = v,

these formulæ become $x = \sqrt[3]{\frac{E_d\, v^2\, A^2\, SRr}{25w\,(v^2\, SR + V^2\, r - 2Vv\sqrt{SRr})}}$ ...(12) B.

or if R = r

$$x = \sqrt[3]{\frac{E_d\, v^2\, A^2\, SR}{25w\,(v^2\, S + V^2 - 2Vv\sqrt{S})}} \ \ldots\ldots\ldots\ (13)\ B.$$

Note E.

There is another method of calculating scantlings for permanent structures, (brought to notice for the first time in Professional Papers No. 1 [Second Series] for July 1871), that is to substitute the strength formula (b or d)

$$= \left(\sqrt[3]{\frac{1}{r^2}} \text{ or } \sqrt[3]{r}\right) \times \sqrt[3]{\frac{s}{2P}} \times \sqrt[3]{w\, L^2}$$

such a value of s (the factor of safety) that the deflection under the proposed load may not exceed $\frac{1}{40}$th inch per foot of span. Equating the depths obtained under similar conditions of load and span from formulæ (3) and (4) the following result is obtained,

$$\left(rw \times \frac{25}{E_d}\right)^{\frac{1}{4}} \times L^{\frac{3}{4}} = \left(rs\, w \times \frac{1}{2p}\right)^{\frac{1}{3}} \times L^{\frac{2}{3}} \text{ whence}$$

$$s = \left(\frac{25}{E_d}\right)^{\frac{3}{4}} \times 2p \times \left(\frac{L}{wr}\right)^{\frac{1}{4}} \ \ldots\ldots\ \ldots\ldots\ (14).$$

This is the same result as that arrived at in equation (iii), page 217 1st Volume of the Roorkee Treatise on Civil Engineering (2nd Edition); (if s be written for n, and w for sw this will be evident).

The strength formula as written above, is not in a convenient form for practical use with varying values of s; and must be changed into the form of formula (ii), $bd^2 = wL^2 \cdot \frac{s}{2p}$. The equation for s may be broken up into four factors.

(*a*). $\left(\frac{25}{E_d}\right)^{\frac{3}{4}} \times 2p$ depending on the kind of wood.

(*b*). $\sqrt[4]{L}$ depending on the span.

(*c*). $\sqrt[4]{w}$ " " load per running foot of the beam.

(*d*). $\sqrt[4]{r}$ " " relation of breadth to depth fixed upon.

Values of these for several kinds of wood, and for the loads and spans in ordinary use are tabulated below

$$S = \frac{(a)\,.\,(b)}{(c)\,.\,(d)}.$$

Tabular numbers for wood selected.

Wood.	Sál.	Teak.	Deodar.*	Fir.
(*a*) values of $\left(\frac{25}{E_d}\right)^{\frac{3}{4}} \times 2p =$	33·663	37·313	31·623 A 27·581 B	28·742

Tabular number for span.

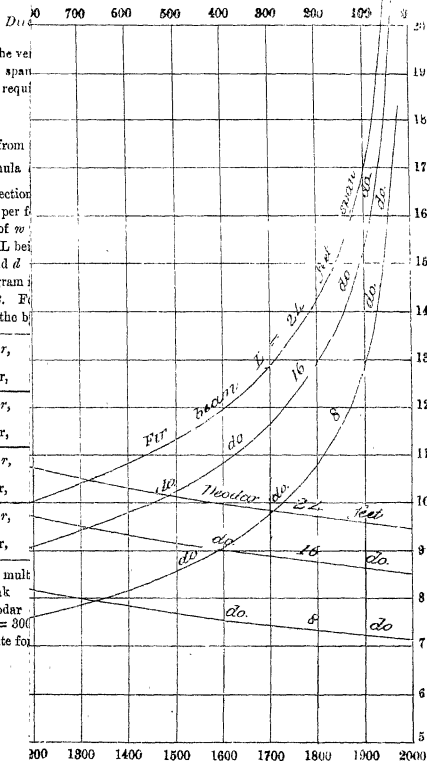
$L =$	(*b*) $\sqrt[4]{L} =$
1	1·000
2	1·188
3	1·316
4	1·414
5	1·494
6	1·563
7	1·625
8	1·680
9	1·732
10	1·780
11	1·820
12	1·861
13	1·898
14	1·934
15	1·968
16	2·000
17	2·030
18	2·060
19	2·087
20	2·115
21	2·141
22	2·166
23	2·189
24	2·213
25	2·236

Tabular number for load.

$w =$	(*c*) $\sqrt[4]{x} =$
25	2·236
50	2·661
75	2·943
100	3·162
125	3·345
150	3·500
200	3·762
250	3·976
300	4·162
350	4·324
400	4·472
450	4·605
500	4·729
600	4·949
700	5·143
800	5·318
900	5·477
1000	5·624
1200	5·886
1400	6·116
1600	6·324
1800	6·514
2000	6·688

Tabular number for the ratio of depth to breadth selected.

$\frac{d}{b} = r =$	1	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{7}{5}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{7}{4}$	$\frac{9}{5}$	$\frac{15}{8}$	$\frac{2}{1}$
(*d*) $\sqrt[4]{r_1} =$	1	1·058	1·075	1·088	1·109	1·137	1·149	1·159	1·170	1·187

* E_d taken at 2,600 for A, and 3,000 for B.

To take one or two examples.

A deodar beam 16 feet span is loaded with 800 lbs. per running foot, scantling required, the depth being made twice the breadth.

$$s = \frac{31\cdot623 \times 2}{5\,318 \times 1\cdot187 = 6\,32} = 10.$$

(reference to diagram *Plate* LI.,) will show that this value of s is correct)

Then $bd^2 = \frac{800 \times 256 \times 10}{1000} = 2048 = 4b^3$ whence $b = 8$ inches, and $d = 16$ inches. The same result could have been more simply obtained direct from the deflection formula thus, $d = \frac{\cdot376 \times 8}{\cdot188} = 16$ inches.

A kurrie (sál) 12 feet bearing is loaded with 150 lbs. per running foot, scantling required, depth being $\frac{3}{2}$ times the breadth.

$$s = \frac{33\cdot663 \times 1\cdot861}{3\,5 \times 1\cdot109 = 3\cdot89} = 16\cdot1.$$

$$\text{then } bd^2 = \frac{9\,b^3}{4} = \frac{150 \times 144 \times 16\cdot1}{2 \times 880} = 198.$$

whence $b = 4\cdot447$ and $d = 6\cdot671$.

Reference to the diagram shows that the scantling of the kurrie should be found by the "deflection" formula

$$\text{whence } b = \frac{\cdot197 \times 6\cdot45}{\cdot286} = 4\cdot45,$$

$$\text{and } d = 6\cdot67.$$

The latter method of finding the scantling is far simpler and easier than the former, although as far as regards the result, it is indifferent which of them is adopted.

The writer is aware that there are theoretical objections to the method of calculating the scantlings of beams by the "strength formula" with a variable factor of safety as described in this note. Still although theoretically defective, the method has its advantages, and is extensively used by many officers, s being usually assumed at a probable value, and not calculated by formula (14). A diagram *(Plate* LII.*)* is appended, by which s can be found at sight, with quite sufficient accuracy, for deodar and fir, and with the aid of multipliers, for sál and teak. It is scarcely necessary to observe that for permanent structures s should never be assumed less than 10.

W. H. M.

No LVIII.

WIRE-ROPE-WAY FOR MOUNTAIN TRAFFIC.

"Suggestions for an economical plan for carriage of goods from the Plains to Hill Stations."

In an article in the July number of the "Papers," entitled the "Mountain Tramway," it is proposed to utilize the power existing in the downward rush of hill streams for propelling traffic upwards on an Inclined Tramway.

The idea is certainly an ingenious one, but there are many reasons opposed to its being carried into practice.

For working up goods from the foot of the hills to the Hill Stations, the plan described below appears to me a much simpler and more practical one, the motive power being always ready to one hands, and in unfailing quantities. The principal feature in this plan is the utilization of the stored up power existing in the material composing the hill tops, which might be used in conjunction with a Wire-rope-way, suspended between prominent points from the hill tops to the plains.

Take for example Mussoorie, which is the only hill station of which I have had any experience. The most convenient sites for the end stations having been fixed, prominent points 1,500 to 2,500 feet apart should be chosen, on the shortest available route, which I estimate, would be about four miles. About nine intermediate stations would therefore be required; at each station there should be a wheel firmly fixed in a vertical axis, about 4 feet diameter with a deep groove on the outside. At each intermediate station there should be two such wheels. From station to station, there should be working round the wheels an endless wire rope, of the strongest construction and able to bear about 6 maunds within a margin

of safety. The action of the rope and wheels from station to station should be quite independent each of the other, by which the possibility of accidents would not only be lessened, but the damage done, if one were to happen, would be localised, and therefore reduced to a minimum. The goods should be carried in large boxes or crates suspended from the endless ropes.

We will suppose that the way, boxes, &c., are all ready, with a box at each station loaded up with stones or gravel, and that it has been found by experiment what weight of goods in a box at the lower wheel, a box loaded with a fixed quantity of stones at the upper wheel, between any two stations, is able to pull up. The goods being loaded at the lower station, the man then loosens the rope, and away they go to the second station, when it is unhooked and fastened on to the second rope, and so on up to the top.

There should be a brake worked by a "governor" on each upper wheel, to regulate the speed. This and other details for return goods require working out of course, but the above is a simple sketch of the proposed plan, which with modifications might be suited to other localities besides the one alluded to.

The cost of a line of wire-way with all the necessary apparatus similar to that above described, from Rajpoor to Mussoorie, would be, from a rough estimation I have made, about Rs. 12,250.

The cost of working it would be Rs. 21 per day, allowing for superintendence at the rate of Rs. 300 per month.

The present charge for goods from Rajpoor to Mussoorie is 7 annas per maund, which rate I would lower to 4 annas per maund : allowing for 200 maunds per day for six months in the year only, the yearly income at this rate will be, (after deducting working expenses) Rs. 5,220, without taking any credit for return goods. This would be between 40 and 50 per cent., taking what it must be allowed is a very moderate view of the possible earnings. A single way as above, would be capable of carrying 360 maunds daily, and the working expenses would not be appreciably increased; in full work it would therefore pay cent. per cent.

In the transport of commissariat stores to the hill stations, a great saving might be caused by the adoption of the above plan, or a modification of it. The idea of a wire-way is not original, and suggested the above plan to me.

W. B.

No. LIX.

EARTHWORK ESTIMATES.

[Vide *Plate* No. LIII.]

By Captain A. M. Brandreth, R.E.

The following plan may be useful. The given quantities of a section of channel are as below. Opposite are put the letters taken to represent them in the general case, and figures in the example given.

Bottom width, ...	B	50
Road width right in excavation, ...	B_1	20
" " left "	B_2	10
Bank top width, right, ...	B_3	25
" " " left, ...	B_4	15
Side slope of cutting, ...	S	1 to 1
" " " bank, ...	S_1	1·5 to 1
Height of road over bed, ...	D	8
Depth at which cutting equals bank, ..	E	4·25
Distance between stations, ...	L	1000

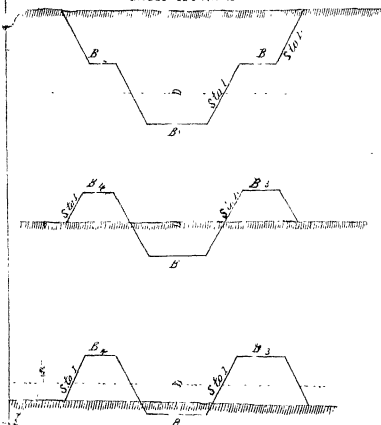
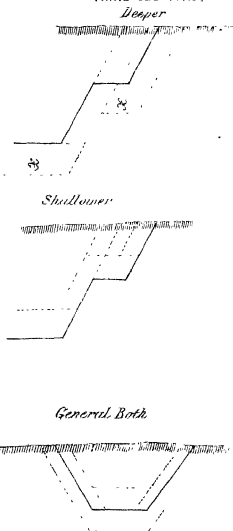
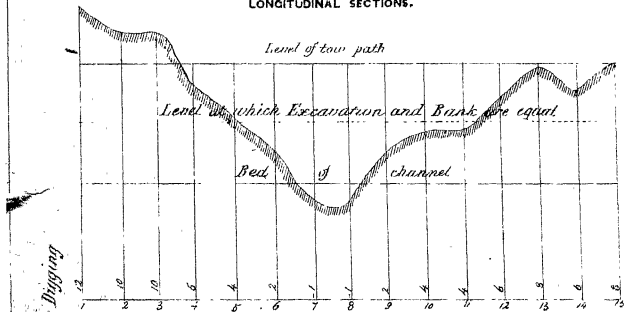
Then if a, b, c, be the depths of digging at the several stations, the cross section at a will be

$Ba + Sa^2 + (B_1 + B_2)(a - D)$, and similarly where depth is b. $Bb + Sb^2 + (B_1 + B_2)(b - D)$, similarly for c, and so on, and the whole content being the sum of half the first and last section, and all the others, multiplied by the common length will be

$$L \, . \, B \, . \left(\frac{a}{2} + b + c + \ldots\ldots\ldots\ldots + y + \frac{z}{2} \right)$$

$$+ \, . \, S \, . \left(\frac{a^2}{2} + b^2 + c^2 + \ldots\ldots\ldots + y^2 + \frac{z^2}{2} \right)$$

$$+ L(B_1 + B_2) \left\{ \left(\frac{m}{2} + n + \ldots\ldots\ldots\ldots + r + \frac{s}{2} \right) - (n-1)D \right\}$$

EARTHWORK ESTIMATES.
CROSS SECTIONS.
TRIAL SECTIONS.
Deeper
Shallower
General Both
LONGITUDINAL SECTIONS.
Level of tow path
Level at which Excavation and Bank are equal
Bed of channel
Digging
12 10 10 6 4 2 1 1 2 4 4 6 8 6 8
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

where n is the number of terms in which the depth of digging is greater than D.

When the depth of digging is less than E, the banks are in excess of the excavation, and must be calculated for the total quantity, the channel being also calculated, and the quantity subtracted from the total, to show the quantity that has to be dug from borrow pits.

If a, b, c, be the height of the banks, then the area of the sections will be

$$(B_3 + B_4)\, a + 2 \,.\, S_1\, a^2$$
$$(B_3 + B_4)\, b + 2\, S_1\, b^2$$

and so on, and the total will be

$$L\,.\,(B_3 + B_4)\left(\frac{a}{2} + b + \ldots\ldots\ldots\ldots + y + \frac{z}{2}\right)$$
$$+\ 2\,.\,L\,.\,S_1\,.\left(\frac{a^2}{2} + b^2 + \ldots\ldots\ldots\ldots + y^2 + \frac{z^2}{2}\right)$$

Call the five series, M, N, O, P, and W to shorten matters; the point is to find the value of these series, an example of 15 stations is given, and worked out, simple figures taken, but with Barlow's table of squares, it does not matter what they are, but one place of decimals should never be exceeded in *any* estimate for earthwork. No further explanation seems necessary, the only point is to take the estimate in separate sections when in excess embankment. If the section is irregular, and the depth of digging near E for some time, so that it seems many sections of estimate are necessary, take a good long length, and calculate whole excavation and embankment, but the details of working will be evident on trial.

The advantages claimed are facility of check. Given a detailed estimate to check, it would it is believed save labor to take it in sections, and work it out afresh by this method, and only check in detail the sections that are wrong. The centre portion, slopes, and tow-paths are all given separate, which is sometimes convenient. The objection is that it does not give the detail in each 1000 feet length, but this is a labor that should not be gone into till the estimate is sanctioned in these centralised days.

There is further a great advantage. In laying out the bed of a channel on a ground section, and arranging the position of the falls, it is often a question whether it would not be better to lower or raise a particular reach and to be able readily to get at the difference in excavation is convenient. This can be easily done on this plan; thus, see the cross sections in plan, the whole lines say are as the excavation has been estimated, and the

dotted as it is proposed to alter, *i. e.*, to raise or lower the bed x feet, then the extra or less in sides is S . x . L . M, and the rest is (B + S x) x. n. L, or (B − S x) x . n . L, and as M is already known, the calculation is a very simple one. Thus to raise the bed in r each from station 5 to 11, by 2 feet 1 × 2 × 1000 × 12, gives the sides, and (50 + 2) × 2 × 7 × 1000 the rest in excess, following same order as in general expression above.

If there are tow-paths, the difference for the length they are calculated for is (B_1 + B_2). x multiplied by the length, but as the excavation for them will be longer or shorter than before, according as the bed is lowered or raised, the easiest plan will be to take out the quantity afresh from the estimate.

The whole complication, if there is any in above general case, is from the generality of the case. If as would be the case usually only the actual quantity was wanted, the excavation from 5 to 11 in example would not have been calculated at all. It should be a rule that applies equally to all earthwork estimates that the reduced levels should be entered to nearest tenth, and the half of an odd tenth should be the whole tenth above its accurate value.

An estimate for 44 miles of earthwork, taken out in detail to sections 100 feet apart, and two places decimals, was made out again by undersigned taking the digging to the nearest half foot at every 1000 feet only, and the difference was only 2 in 130, and that it is believed was an error in the detail estimate. The labor wasted in earthwork calculations is believed to be very considerable.

ESTIMATE OF CROSS SECTIONS.

No. of station.	Depth of Excavation.	Excavations. M.	Excavations. N.	Excavations. O.	Bank. Height of bank.	Bank. P.	Bank. Q.	Remarks.
1	12	6	72	6				
2	10	10	100	10				
3	10	10	100	10				
4	6	6	36	0				
5	4	2	8					
		36	316	26				
5	4	2	8		4	2	8	
6	2	2	4		6	6	36	
7	—1	..	..		9	9	81	
8	—1	..	..		9	9	81	
9	2	2	4		6	6	36	
10	4	4	16		4	4	16	
11	4	2	8		4	2	8	
		12	40			38	266	
11	4	2	8					
12	6	6	36					
13	8	8	64					
14	6	6	36					
15	8	4	32					
		26	176					

ABSTRACT ESTIMATE OF QUANTITY.

Letter standing for series.	Value of series.	Constant width or ratio of slope.	Constant length.	Content.	Total.	Remarks.
Stations 1 *to* 5.						
M	36	50	1000	1,800,000		
N	316	1	„	316,000		
O	26					
(N — 1)D,	24					
Difference.	2	30	„	60,000	2,176,000	
Stations 5 *to* 11.						
P	38	40	1000	1,520,000		
Q	266	3	„	798,000	2,318,000	
M	12	50	„	600,000		
N	40	1	„	40,000		
Total channel, ..				640,000		
Difference in borrow pits, ..				1,678,000		
Stations 11 *to* 15.						
M	26	50	1000	1,300,000		
N	176	1	„	176,000	1,476,000	
Grand Total excavation, ..					5,970,000	

No. LX.

ON THE PROFILE TO BE GIVEN TO WALLS RETAINING WATER.

By E. L. Asher, Esq., *Executive Engineer.*

[Second Article].

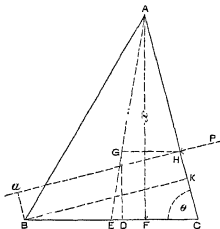
An abstract of the results of this investigation, containing a general review of the propositions by which they have been established, was published in a late issue. The object of this anticipation was two-fold. To present matters in a sufficiently facile and tangible form to obtain readers, and to throw results into a convenient form for practical use. It has not been thought desirable to mutilate this investigation for the mere avoidance of repetition. It is presented complete, and the diagrams are repeated.

The pressure of still water on a retaining plane varies as the square of the plane's (vertical) depth. Its arm of moment round *any* point* is a multiple of the depth. Therefore the moment varies as the cube of the depth, and its initial value is *o*.

The weight of a triangular profile varies as the square of its depth. Its arm of moment round the heel is a multiple of the depth. Therefore the moment varies as the cube of the depth, and its initial value is *o*.

These identical conditions cannot be established in the case of any geometrical profile except the triangle.

* Not necessarily in the plane.

Therefore, for a consideration purely of statical equilibrium, the triangle is the true profile for a wall to retain still water.

Let ABC be a material triangle resisting the pressure of water, and weighing w' to the square unit.

And let water weigh w to the square unit.

Let the base BC $= b$, and let P represent the resultant water pressure, and let θ be the inclination of the water face to the horizontal, and G the centre of gravity, and let x be the vertical height or depth.

Then we have, by known principles of hydrostatics and of mechanics generally, and of geometry,

$$\frac{w'bx,}{2} \times \text{BD} = \frac{wx^2}{2} \operatorname{cosec}\theta \times \text{B}a,$$

$$\text{BD} = \text{BE} \pm \text{ED} = \frac{b}{2} \pm \text{ED} = \frac{b}{2} \pm \tfrac{1}{3}\,\text{EF},$$

$$\text{EF} = \pm\,(\text{CE} - \text{CF}) = \pm\left(\frac{b}{2} - \text{CF}\right).$$

(the alternative signs are necessary to include the case, where the vertical AF should fall on the opposite side of the central line AE—the result is the same in both cases),

$$\text{BD} = \frac{b}{2} \pm \frac{1}{3}\left(\frac{b}{2} - \text{CF},\right) \qquad \text{CF} = x\cot\theta,$$

$$= \frac{b}{2} \pm \frac{1}{3}\left(\frac{b}{2} - x\cot\theta\right)$$

(But as $\frac{b}{2} - x\cot\theta$ carries its own sign according to the two cases referred to, this becomes simply, the following):—

$$\text{BD} = \frac{b}{2} + \frac{1}{3}\left(\frac{b}{2} - x\cot\theta\right)$$

$$= \frac{2\,b - x\cot\theta}{3},$$

$$\text{B}a = \text{CH} - \text{CK} = \frac{x\operatorname{cosec}\theta}{3} - b\cos\theta.$$

Hence, the equation of stability becomes

$$\frac{w'bx}{2}\;\frac{2\,b - x\cot\theta}{3} = \frac{wx^2}{2}\operatorname{cosec}\theta\left(\frac{x\operatorname{cosec}\theta}{3} - b\cos\theta.\right)$$

which reduces to the following, calling

$$\frac{w'}{w} = n, \text{ the specific gravity of the triangle,}$$

$$x^2 \cot^2\theta + (n - 3)\, bx \cot\theta + x^2 - 2nb^2 = o,$$

$$\text{or } 2nb^2 - (n - 3)\, x \cot\theta \,.\, b - x^2 (1 + \cot^2\theta) = o,$$

$$\text{or } b = \frac{(n - 3)\cot\theta \pm \sqrt{(n - 3)^2 \cot^2\theta + 8n\,(1 + \cot^2\theta)}}{4n}\, o.$$

It is evident, then, that there must be some value of θ which, introduced into this expression, will make b, and consequently the profile, a minimum.

To find this, differentiate and equate to o we get

$$(n - 3)\operatorname{cosec}^2\theta \pm \frac{2\,(n - 3)^2 \cot\theta \operatorname{cosec}^2\theta + 16n \cot\theta \operatorname{cosec}^2\theta}{2\sqrt{(n - 3)^2 \cot^2\theta + 8n\,(1 + \cot^2\theta)}} = o,$$

whence, after reductions,

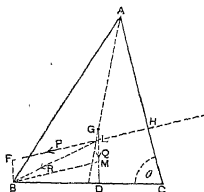
$$\cot\theta = \pm \frac{3 - n}{\sqrt{n^2 + 2n + 9}} \quad \ldots\ldots\ldots\ldots (1).$$

and substituting this in the equation of equilibrium, we get on reduction,

$$b = \frac{2x}{\sqrt{n^2 + 2n + 9}} \quad \ldots\ldots\ldots\ldots (2).$$

$$\text{and } Fc, \text{ the sub-cotangent} = \pm \frac{(3 - n)\, x}{\sqrt{n^2 + 2n + 9}} \quad \ldots\ldots\ldots (3).$$

These equations are simple, depending only on the specific gravity of the wall, and they determine a minimum profile of stability, of which the batter of the waterface is the governing principle.

Now let ABC be a minimum profile, and G its centre of gravity, its weight acting vertically in GD, and HF the line of resultant water pressure Compounding these forces, represented by LF and LM at their intersection L. the resultant stress LB must, by our principles of equilibrium, pass precisely through the point B, calling P and Q the components, the magnitude of this resultant R must be

$$R = \sqrt{P^2 + Q^2 + 2PQ \cos FLM}$$

$$\text{now } P = \frac{wx^2}{2} \operatorname{cosec}\theta$$

$$Q = \frac{w'bx}{2}$$

$$\cos \text{FLM} = \cos\theta \text{ by construction,}$$

Substituting for b and θ their values found for the minimum profile, we get

$$R = \sqrt{\frac{w^2x^4}{4}\operatorname{cosec}^2\theta + \frac{w'^2b^2x^2}{4} + 2\,\frac{ww'\,bx^3\operatorname{cosec}\theta}{4}\cos\theta}$$

$$= \frac{x}{2}\sqrt{w^2x^2\operatorname{cosec}^2\theta + w'^2b^2 + 2\,ww'\,bx\cot\theta}$$

$$= \frac{wx}{2}\sqrt{x^2\operatorname{cosec}^2\theta + n^2b^2 + 2nbx\cot\theta}$$

$$= \frac{wx}{2}\sqrt{x^2\left(1 + \frac{(n-3)^2}{n^2+2n+9}\right) + n^2\,\frac{4x^2}{n^2+2n+9} + 2nx\,\frac{2x\,(3-n)}{n^2+2n+9}}$$

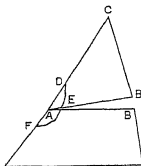
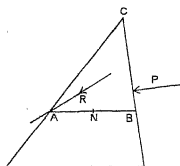
Finally,

$$R = \frac{wx^2}{2}\sqrt{\frac{10n^2 - 16n + 18}{n^2+2n+9}} \quad\ldots\ldots\ldots\ldots\ldots\ldots\ (4).$$

It may also be useful to know the angle which this resultant makes with the horizontal. This is easily found to be

$$\cos\tau = \frac{3-n}{\sqrt{2\,(5n^2 - 8n + 9)}}\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5).$$

It should here be observed, with reference to the minimum profile, that, like any equilibrated triangle, it is in equilibrium at every point of its height, a circumstance which is here evident from b being a simple multiple of x, the same for the same value of θ belonging to the whole face of the wall.

Now a wall exactly balanced as is the minimum profile, will practically fail on the slightest disturbance. Let us examine what will be the effects of such failure. Let it fail at the joint AB, through the resultant R falling just outside A. The

triangle ABC is, it will be observed (or rather *was*) in *stable* equilibrium, because the overthrowing pressure will rapidly diminish, and its resultant line of application be lowered relatively to A, by the elevation of the

apex out of the water, while the arm of gravitation will more slowly diminish on account of its moving through a lesser arc. Some cases, indeed, might exist in which this should not prove the case, but whether the triangle ABC continued its motion or found a new position of equilibrium, the result would be as follows:—

As the movement first occurred, the pressures acting on the joint AB would be more and more lightened on the water side of a neutral axis N, and more and more intensified on the land side of it. This neutral axis would move towards A as the action increased, until at last the joint would open, at which moment N would have reached A, and the whole stress R would be concentrated on the point A. The result, practically, would be that the back of the wall would throw out a wedge DEF, and the triangle ABC would topple over.

It follows, then, that if arrangements were made to ensure the stability of the wall, we have here a limit, immensely exaggerated, of the stress that can, under any circumstances, be brought to crush the material at its back. If, then, we should add on material at the back, of dimensions calculated to resist this crushing force distributed over it, we shall, at the same time, be increasing the stability by retreating the heel, and if it should appear that the amount of this retreat is sufficient to remove all chance of mere disturbance, (and very little should suffice to that, if we assume the water to be still, to which case every other will, by proper allowances, be reduced), it will follow that we have here a sufficient provision for the occurrence of a failure which cannot even occur, and *à fortiori*, a safe provision for security in the integral structure.

It cannot here be too strongly insisted, to prevent objections to the co-efficients which will hereafter be proposed, that this force R is *not* to be considered as an actual force in practice, concentrated at the back, and tending to disintegrate and push it out at that point. In practice, it will really be distributed in some varying ratio along the whole breadth of the joint, and a surprisingly small fraction of it will actually fall on, and about that point. But we are making provision for a hypothetical and impossible, a limiting and immensely extreme case, under which a quantity of material should be disposed at, and about the point E sufficient to resist crushing by a certain stress R, distributed over it, and which once effected must, under our agencies, render it not only improbable but impossible that the wall should be overthrown by these agencies.

Let ABC be a minimum profile. This surface of resistance would evidently be provided by setting off OE, OF from the back, perpendicular to R, so that EF should not be crushed by R distributed over it. We need not, however, trouble ourselves to find this angle, as the result will be ensured by describing a circle of radius OE round O, and making the rib tangential to it. If we do this for every point of the back AB, and draw lines tangential to all these circles; in fact their envelope on either side, we shall have defined the rib of resistance.

Now OE will be calculated as follows:—

We have (equation 4).

$$R = \frac{wx^2}{2} \sqrt{\frac{2(5n^2 - 8n + 9)}{n^2 + 2n + 9}}$$

Let the absolute resistance of the material to crushing be

p_1 lbs. to the square inch.

We will divide this by 8 as an admitted factor of safety for masonry in compression. This safe co-efficient of $\frac{p_1}{8}$ we will call p, which will represent the *safe* pressure per square inch—to avoid mistake.

The breadth of the rib will therefore be in feet,

$$\frac{wx^2}{144 \times 2p} \sqrt{\frac{2(5n^2 - 8n + 9)}{n^2 + 2n + 9}}$$

and the radius, or the off-set from the back will be half this, or

$$\frac{w\,x^2}{144 \times 4p} \sqrt{\frac{2(5n^2 - 8n + 9)}{n^2 + 2n + 9}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

As this is a quadratic expression, the back of the wall will have the curve of a conic section, and we may, for an immediate purpose, consider it a parabolic spandril.

This rib has to be increased to an extent allowing for its own weight tending to crush it. Considering it a parabolic spandril, and resolving it vertically and horizontally, the crushing force will be one-third the area of the parallelogram standing on its base, of height x, and multiplied by w'.

That is, by equation (6), we shall have for the crushing force caused by the weight of the spandril

$$\frac{w\,w'\,x^3}{144 \times 12\,p} \sqrt{\frac{2\,(5\,n^2 - 8\,n + 9)}{n^2 + 2\,n + 9}}$$

adding this to the main crushing stress R (equat. 4), we get for a corrected gross crushing stress—

$$\left(\frac{1}{x} + \frac{w'}{144 \times 6\,p}\right) \frac{w\,x^3}{2} \sqrt{\frac{2\,(5\,n^2 - 8\,n + 9)}{n^2 + 2\,n + 9}}$$

and, finally, for the corrected radius of the rib

$$\left(\frac{1}{x} + \frac{w'}{144 \times 6\,p}\right) \frac{w\,x^3}{144 \times 4\,p} \sqrt{\frac{2\,(5\,n^2 - 8\,n + 9)}{n^2 + 2\,n + 9}}$$

Or, calling ρ the radius, multiplying and dividing by w, and giving it it ordinary value of 62·5

$$\rho = \left(\frac{1}{62{\cdot}5\,.\,x} + \frac{n}{864\,p}\right) \frac{6{\cdot}7816\,.\,x^3}{p} \sqrt{\frac{2\,(5\,n^2 - 8\,n + 9)}{n^2 + 2\,n + 9}} \;\;\ldots\ldots\; (7).$$

The second term of the first factor of this expression is for moderate heights, say under 50 feet, so extremely small, that it may be neglected in such cases, and we shall have for the radius

$$\rho = \frac{0{\cdot}1085\,x^2}{p} \sqrt{\frac{2\,(5n^2 - 8n + 9)}{n^2 + 2n + 9}}, \;\ldots\ldots\ldots\ldots\ldots\; (8).$$

Diagrams 1, 2, and 3 are drawn from equation (7), on the assumption that the *safe* crushing weight $p = 100$ lbs. per square inch. In diagram 1, n is taken at 1·792 as corresponding to brickwork, weighing 112 lbs. to the cubic foot. In diagram 2, n is 2·306, for masonry weighing 144 lbs. to the cubic foot. In diagram 3, n is taken at 2, as an assumption for concrete.*

This theory has now to be tested by considerations of stability founded on failure by sliding, and by results of which the elements are laid down by Professor Rankine in his Applied Mechanics.

It will be seen in that work that the author starts by conceiving a triangular wall fully adjusted for safety, and that this adjustment is supposed to have been effected at the outset by locating the centre of resistance of the joint at a distance q from the bisection of the joint. He then

* For a correction of this process, which does not materially affect results, see addendum to this paper. It will also be observed that the adoption, for the back of the profile, of the envelope of these generating circles is a slight departure from mathematical truth, but a departure on the safe side and quite necessary for simplicity in construction.

calculates the equation of moments, involving two unknown quantities, q and the width t, and eliminates q by laying down a second equation based on the stability of friction. The result is an expression for a wall which shall be safe against overturning and against sliding, which, in the opinion of many, may be all that can possibly be required. To others, however, it may appear that in very lofty dams it is advisable to have security by a compression rib, the design of which has involved the consideration of maximum strains, and the degree to which either method should be applied, will, I think, be apparent from the diagrams I have subjoined.

Professor Rankine's results are worked out on certain special cases, but it will better suit my purposes here to develop his general theorem. The reductions involved being extremely lengthy, I shall only have space here to indicate operations.

Rankine's equations, slightly simplified and adapted, are the following.

$$\frac{t}{x} = \sqrt{a + b^2} - b, \quad \ldots\ldots (9).$$

$$\frac{t}{x} = m \frac{1 - \tan\phi \tan j}{\tan\phi}, \quad \ldots\ldots (10).$$

$$a = \frac{m}{3(q \pm q')} \sec^2 j, \quad \ldots\ldots (11).$$

$$b = m \frac{\frac{q}{2} + \frac{1}{4}}{q \pm q'} \tan j, \quad \ldots\ldots (12).$$

t = bottom width.

x = height.

j = inclination of the face to the *vertical*.

ϕ = limiting angle of repose for masonry, taken at $\tan\phi = 0{\cdot}74$.

m = the reciprocal on n, the specific gravity.

q = a variable, = the ratio of the distance from the centre of resistance to the bisection of the joint, to the whole breadth of the joint, or t.

q' = the ratio of the distance from the perpendicular dropped on the joint from the centre of gravity, to the bisection of the joint; to the breadth t, of the joint.

It is evident that q' contains its own sign, and hence the alternative signs will be dropped.

I now proceed to develop the general equations. First to determine q'

We shall clearly have—

$$q' = \pm \frac{\frac{1}{3}\overline{AB}}{t} \quad AF = \frac{1}{3}\,\overline{AB}$$

$$AB = \sqrt{\overline{AC}^2 - x^2}.$$

$$AC^2 = \overline{AD}^2 + \overline{DC}^2 - 2\,\overline{AD}\,.\,\overline{DC}\,.\cos\overline{ADC}.$$

$$= \frac{t^2}{4} + \overline{DC}^2 - t\,.\,\overline{DC}\sin j.$$

$$DC = x \sec j.$$

$$\therefore AC^2 = \frac{t^2}{4} + x^2 \sec^2 j - tx \tan j.$$

$$\therefore AB = \sqrt{\frac{t^2}{4} + (\sec^2 j - 1)\,x^2 - tx \tan j}.$$

$$= \frac{t}{2} - x \tan j.$$

$$\therefore q' = \pm \frac{\frac{1}{3}\left(\frac{t}{2} - x \tan j\right)}{t}$$

$$= \pm\left(\frac{1}{6} - \frac{\tan j}{3}\,\frac{x}{t}\right) \ldots\ldots\ldots\ (13).$$

Squaring equation (9) we get—

$$\frac{t^2}{x^2} + 2b\,\frac{t}{x} - a = o.$$

giving a and b their values, in which q' is replaced by its value as found above, (equation 13).

$$\frac{t^2}{x^2} + \frac{6m\left(\frac{q}{2} + \frac{1}{4}\right)\tan j}{3q + \left(\frac{1}{2} - \tan j\,\frac{x}{t}\right)}\cdot\frac{t}{x} - \frac{m \sec^2 j}{3q + \left(\frac{1}{2} - \tan j\,\frac{x}{t}\right)} = o$$

This becomes the following:—

$$\frac{t}{x} = \frac{-\left\{6m\left(\frac{q}{2}+\frac{1}{4}\right)-1\right\}\tan j \pm \sqrt{\left\{6m\left(\frac{q}{2}+\frac{1}{4}\right)-1\right\}^2 \tan^2 j + 4m\sec^2 j\left(3q+\frac{1}{2}\right)}}{2\left(3q+\frac{1}{2}\right)} \quad (14)$$

Substitute this value in equation (10), and we get

$$\left[(3q+\tfrac{1}{2})\,2m\,\frac{1-\tan\phi\tan j}{\tan\phi} + \left\{6m\left(\frac{q}{2}+\frac{1}{4}\right)-1\right\}\tan j\right]^2 = \left\{6m\left(\frac{q}{2}+\frac{1}{4}\right)-1\right\}^2 \tan^2 j + 4m\sec^2 j\,(3q+\tfrac{1}{2}).$$

Whence, after lengthy reductions, we draw the following value of q.

$$q = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

in which

$$\left.\begin{array}{ll} a = 36\,m\,(\omega^2 + \omega \tan j.) & \alpha = 12\,(2m - 1), \\ b = \alpha\,\omega \tan j - 12 \sec^2 j + 12\,m\omega^2. & \beta = 2 - 3m, \\ c = m\omega^2 - \beta\,\omega \tan j - 2 \sec^2 j. & \omega = \frac{1 - \tan\phi \tan j}{\tan\phi} \end{array}\right\} \quad \ldots\ldots\ldots (15).$$

And q being determined from these equations, we can find $\frac{t}{x}$ by substituting its value in equation (14) simplified as follows:—

$$\left.\begin{array}{l} \frac{t}{x} = \frac{-B \pm \sqrt{B^2 - 4Ac}}{2A} \\ A = 3q \times \frac{1}{2}. \\ B = \left[6m\left(\frac{q}{2} + \frac{1}{4}\right) - 1\right] \tan j \\ c = -m \sec^2 j. \end{array}\right\} \ldots\ldots\ldots\ldots (16).$$

Now the limit of value of q is, as a result of its definition, $q = \frac{1}{2}$. That is to say, such is the limit of the values of q, within which equation (16) has any rational significance.

If we insert this limiting value of q in equation (16) we get

$$A = \frac{3}{2} + \frac{1}{2} = 2.$$

$$B = \left(\frac{6m}{2} - 1\right) \tan j = (3m - 1) \tan j.$$

$$C = -m \sec^2 j.$$

$$\frac{t}{x} = \frac{(1 - 3m) \tan j \pm \sqrt{(9m^2 + 2m + 1) \tan^2 j + 8m}}{4} \ldots\ldots\ldots (17).$$

Also, if we insert the value $q = \frac{1}{2}$ in equation (15), we obtain

$$\tan j = \frac{-2\,(m + 1) \tan \phi \pm 2 \sqrt{(m - 1)^2 \tan^2 \phi + 8m^2}}{4m \tan\phi} \ldots\ldots\ldots (18).$$

Now the greater the value of q, the less will be the value of t, and consequently the area of the profile.

That is, the minimum profile under frictional conditions will be that corresponding to the maximum value of q, or $q = \frac{1}{2}$.

Therefore equation (18) gives the value of tan j for this minimum profile, m and ϕ being given in every case, and if we insert this value of tan j in equation (17) that equation will determine the corresponding value of the base, thus completely determining the profile.

We have here all that is necessary to enable us to realise, practically and fully, the law of profiles designed on the basis of frictional stability. The calculations are extremely lengthy, and I shall confine myself here to the nett results only.

I have considered, then, a structure of masonry weighing 144 lbs. to the cubic foot, and in which, consequently, $m = 0{\cdot}433$, and I have taken an ϕ at 0·74, and my results are as follows:—

Value of tan j.	j or corresponding approximate angle with vertical.	θ or corresponding approximate angle with horizontal.	Value of q.	Ratio of base to height.	Remarks.
0	0°	90°	0·25480	0·5852	vertical face.
0·1	6°	84°	0·32542	0·5418	
0·2	11½°	78½°	0·41260	0·4985	
0·3	17°	73°	increasing.	decreasing.	
0·358	19½°	70½°	0·50000	0·4680	minimum.

This establishes the conclusion that of equally effective walls in respect of frictional stability, those are more and more economical which have an increasing departure of their water face from the vertical, and that, within the limits of this theory, the greatest economy is attained where the water face is inclined at about 70½° to the horizontal, at which position the base should be 0·468 of the height, being a saving of 0·1172, or say 11½ per cent. on the wall with a vertical face. These figures, be it understood, being for walls of the precise weight of 144 lbs. to the cubic foot.

I have further compared, for three several classes of work, the mini-

mum profile of rotary stability with this minimum or limiting profile of frictional stability, and my results are as below:—

Class of work.	Assumed weight lbs. per cubic foot.	n.	m.	Cot θ or tan j for minimum profile of rotary stability.	Tan ϕ	θ or approximate angle with horizontal.	Ratio of base to height.		Remarks.
							For rotary stability.	For frictional & rotary stability	
Brickwork, ..	112	1·790	0·559	0·297 to 0·300	0·74	73°	0·503	0·585	
Concrete, (gravel), ..	125	2·000	0·500	0·242	0·74	77°	0·485	0·555	
Masonry, ..	144	2·306	0·433	0·1595 to 0·1600	0·74	80½°	0·460	0·516	

That is to say, the inclination of the water-face in the minimum profile of rotary stability is, in every practical case, such as to bring it within the limits requiring theoretical allowances for friction, and that, to satisfy this criterion, their bases should be increased to the following values, respectively:—

	cot. θ.	b.
Brickwork, ...	0·299	0·585 · x
Concrete, ...	0·242	0·555 · x
Masonry, ...	0·160	0·516 · x

That is, if the frictional criterion be considered a *sine quâ non*. That it need not necessarily be so considered, will be evident from the fact that by canting the courses some 10 or 12 degrees towards the water, we could, at these values of θ eliminate it altogether.

Accordingly, I have plotted on to diagrams 1, 2 and 3, a straight back to the wall which satisfies this criterion. That line it will be seen, falls outside the curve of the rib down to approximate heights, for brick-work concrete and masonry respectively, of 55, 40, and 30 feet. Intersecting the curve at these points, it falls rapidly within it.

That it is no great matter whether or not we satisfy this criterion will be evident on these diagrams from the extremely minute departure of the line in increment, amounting in no case, and that only at one point, to one foot in 16. The gross increase to the wall by its introduction would

be in the maximum case (brick-work), about 2 per cent., and on further consideration, even less.

For, practically, these walls must not terminate in an apex. They must carry a wash wall, and a gangway. They must have at least 3 feet top width. Let us say 4. Plotted on to the profiles, this will probably reduce the increase to little over 1 per cent. and in high dams this percentage will be sunk to practically nothing by distribution over an increasing mass.

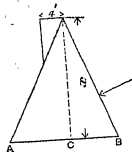
The principles of the design of safe profiles as developed in this essay may, then, so far be summed up as follows, for practical application, and subject to a few provisos respecting only the height x, which will be made in the sequel.

I.

If the constants that have been assumed be practically accepted.

(*a*). If the wall do not exceed certain heights, being

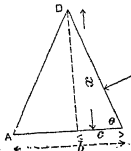
For brickwork,	.. ..	55 feet.
„ concrete,	.. ..	40 „
„ masonry,	.. ..	30 „

make the profile a simple triangle on which

For brickwork, AB $= 0{\cdot}585.\ x$, BC $= 0{\cdot}299\ x$.
„ concrete, AB $= 0{\cdot}555.\ x$, BC $= 0{\cdot}242\ x$.
„ masonry, AB $= 0{\cdot}516.\ x$, BC $= 0{\cdot}160\ x$.

(*b*). If the wall do exceed these heights, let the profiles of diagrams (1), (2), or (3) according to their material, be precisely initated, according to their figurings, adapting the exterior straight back for its upper portion.

II.

If the constants that have been assumed be not practically accepted.

Proceed to draw a minimum profile of rotary stability, in which $b = \frac{2x}{\sqrt{n^2 + 2n + 9}}$ $c = \frac{(3-n)x}{\sqrt{n^2 + 2n + 9}}$

n being the specific gravity of the material. At, every 10 feet of the height, rule a horizontal line, and where it intersects the back AD of the profile describe a circle of radius ρ so that $\rho = \left(\frac{1}{625 . x} + \frac{n}{864p}\right) \frac{6{\cdot}7816x^3}{p} \sqrt{\frac{2(5n^2 - 8n + 9)}{n^2 + 2n + 9}}$ or, for a rougher approximation...

$$\rho = \frac{0{\cdot}1085 x^2}{p} \sqrt{\frac{2\,(5n^2 - 8n + 9)}{n^2 + 2n + 9}} \text{ if the height is } < 50$$

n being the specific gravity of the material.

p the *safe* compressive strain per *square inch* of the material.

x the height, or rather, depth.

Tangent lines drawn to all these circles will define, on the outside, the back of the wall, and on the inside, the inside limit of the rib, to be used or not, as details of construction may require.

If the courses are to be canted, the profile may be so far considered complete, otherwise increase it for frictional stability as follows :—

$$\text{Calculate } \tan j = \cot \theta = \frac{3 - n}{\sqrt{n^2 + 2n + 9}}$$

Calculate a quantity q as follows, inserting this value of $\tan j$, and calling $\tan \phi$ (the limiting angle of repose) 0·74 on the authority of Rankine, and m being the *reciprocal* of the specific gravity of the material.

$$q = \frac{-b + \sqrt{b^2 - 4\,ac}}{2a}$$

$$a = 36\,m\,(\omega^2 + \omega \tan j),$$
$$b = \alpha\,\omega \tan j - 12 \sec^2 j + 12\,m\,\omega^2,$$
$$c = m\,\omega^2 - \beta\,\omega \tan j - 2 \sec^2 j,$$
$$\alpha = 12\,(2\,m - 1),$$
$$\beta = 2 - 3\,m,$$
$$\omega = \frac{1 - \tan\phi \tan j}{\tan \phi},$$

being very careful about signs.

Then, with the resulting value of q, enter the following equation, giving $\tan j$ its value as found, and remembering that $\sec^2 j = 1 + \tan^2 j$.

$$\frac{t}{x} = \frac{-B + \sqrt{B^2 - 4AC}}{2A},$$
$$A = 3q + \tfrac{1}{2},$$
$$B = \left[6\,m\left(\frac{q}{2} + \frac{1}{4}\right) - 1\right] \tan j,$$
$$C = -\,m \sec^2 j.$$

The result will be a fraction, the ratio of the base to the height. The value of the base thus found is to be set back from the toe of the profile under correction, and the extremity joined to the vertex of the wall,

forming its back, and the corrected back of the profile will follow the curve below, and the straight line above the intersection.

All these calculations will, of course, be effected with logarithm tables.

These profiles having been designed for perfectly still water, require two corrections, viz.:—

(1). For waves.

(2). For currents.

Waves.

The waves which occur on minor bodies of inland water are inconsiderable. A very usual height of splash wall is 4 feet, and we may safely fix this as the limit of height of undulation above mean level.

The effect of a wave will be to momentarily increase the head of water on the structure. It would seem, therefore, that a full provision would be to design the wall as for a depth of 4 feet greater than the proposed high water level will give.

It should be borne in mind that, as a reservoir should always have overfalls strictly calculated to pass off water of a certain maximum depth on their crests, it is this highest surface, and not the crest level of the highest overfall that is to be assumed as the primary high-water level, and to this, then, is to be added 4 feet for the effect of waves.

Currents.

It is not proposed here to consider the case of retaining walls acting as overfalls. These, as requiring the particular condition of plumb, or nearly plumb, backs, to avoid wear at their feet, involve special considerations, which will be the subject of a future investigation.

But such currents as may be either the reflex of a main current towards an overfall, or the effects of a main current on the immediate flanks of an overfall will be here considered.

The maximum observed effect in lbs. pressure of the normal impact of water having velocity v, on a square foot of surface, is 4 times the hydrostatic pressure of a column of that base, and having the height due to the velocity v. Consequently, if v be the velocity of the current, the maximum additional pressure of impact on the wall may be held to be produced by an increment in head of

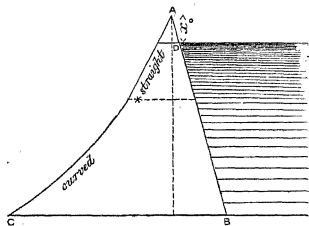
$$4\frac{v^2}{2g}, \text{ or say } \frac{v^2}{16} \text{ in feet.}$$

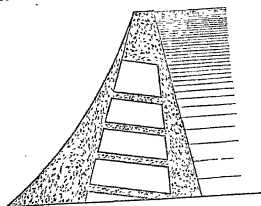
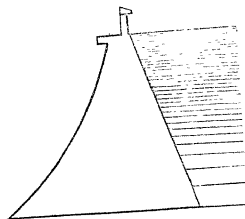
The effect, then, of a reflex current may be considered so small as to be practically not worth considering, and that of a direct current on the flanks of an overfall may be taken as some fraction unknown of the surface velocity over the fall. This is a function of the maximum depth on crest. Calling this depth h, we may say that the maximum velocity is $\sqrt{2gh}$, and we shall have

$$v = a \sqrt{2gh}$$

in which a is some fraction, which can only be settled by experiment. But when we consider the case of a high overfall, it is very evident that the mean velocity of what must be, after all, an induced current or eddy, counted distributively over the whole back of the wall, must be an extremely minute fraction of the velocity of the escaping body of water. Now in an ordinary overfall of 2 feet on the sill, the velocity may be taken at 10 feet per second, and if we take v at one-fourth of this, we shall undoubtedly be far above the mark. In such case we should have $v = 2\frac{1}{2}$, or let us say 3, and $\frac{v^2}{16} =$ about 6 inches.

If, then, we add on a foot to the working head, we shall have made safe provision for currents.

In fine, we arrive at a gross correctional addition to the head, which I have estimated at 5 feet, but which any one may fix at x_0, according to his particular judgment, guided by these principles, and this correction is to be applied as follows :—

An indefinitely deep profile ABC having been projected according to the principles which have been laid down, set off a height AD $= x_0$, and then terminate the profile by a horizontal line which will be considered the high water level of the work. On this should be erected, the wash-wall, and if the space be small for this and the gangway it may be economically provided by corbelling the back as per accompanying sketch.

Now it will be evident from all that has been shown, that the principal destructive stresses would come upon the back of the wall. Accordingly it would seem that by making the compression rib of the best work, and connecting it at horizontal and vertical intervals, by bond courses with similar work on the face designed to resist percolation, and by making arrangements for thorough drainage of the interior, we might use material of the very roughest character for the filling. In fact, it will be evident that such a wall is here assimilated to a cantilever or girder, which in effect it is, and the disposition of the sounder material entirely corresponds to that of flanges and web of a girder, and does the same duties. It would, in fact, be a good measure, were it not for the expense, to bond the facework vertically with hoop iron, as it would positively be in tension in the case of any tendency to failure. However this investigation is not intended to go beyond the establishment of a normal profile, which profile will be departed from, added to, and worked up in design, subject to the various conditions of work and the practical insight and discretion of the Engineer.

ADDENDUM.

To ensure simplicity in results, the preliminary calculation of the half rib area for correction of the crushing force is necessarily rough, but it is approxmate.

It has, however, been observed that it constituted a doubtful feature in the investigation that the weight of the half rib had been estimated on a breadth assumed, or rather deduced from conditions which were imperfect in not having embraced this weight. The following calculation

has, therefore, been made in revision of the former one, and, while it will be seen from the example given, that the difference of results justifies, by its minuteness, the method originally followed, it will yet be advisable to adopt this corrected value of ρ on account of its greater simplicity.

Let ρ be the half breadth sought. Then the crushing force due to the weight of the parabolic spandril assumed will be $\rho \frac{x w'}{3}$

Adding this to the crushing stress R, found in equation (4), the corrected gross crushing stress will be

$$\rho = \frac{x w'}{3} + \frac{w x^2}{2} \sqrt{\frac{2(5 n^2 - 8 n + 9)}{n^2 + 2 n + 9}}$$

and since the safe crushing strain per square inch is p, the breadth of the rib will be $\frac{1}{144. p} \times$ crushing stress, and since ρ = half of this breadth

$$\rho = \frac{1}{288 p} = \left(\frac{x w'}{3} + \frac{w x^2}{2} \sqrt{\frac{2(5n^2 - 8 n + 9)}{n^2 + 2 n + 9}}\right)$$

which reduces to the following (making $w = 62{\cdot}5$ and $\frac{w'}{w} = n$

$$\rho = \frac{3 x^2}{2 (13 824 p - n x)} \sqrt{\frac{2(5 n^2 - 8 n + 9)}{n^2 + 2 n + 9}}$$

This should supersede the value of ρ given in equation (7).

To show how trifling is the difference in any case, let us take height

$(x) = 50$ feet, $n = 2$, $p = 100$.

Equation (7) gives $\rho = 3{\cdot}602$.

Revised equation gives, $\rho = 2\ 622$, or about a quarter of an inch difference.

E. L. A.

No. LXI.

ESSAY ON THE GEOLOGY OF KUNKUR.

[Vide *Plates* Nos. LIV. and LV.]

By A. Nielly, Esq., *Assistant Engineer*, S.W.D., B.D.C.

The origin of the mineral called kunkur, which is spread as a sub-alluvium stratum over such a large proportion of India, has not yet, as far as I am aware, been thoroughly investigated.

David Page in his hand-book of geological terms, merely states that it seems to correspond in point of time to the boulder drift formation, and adds to this information a general description of it by Ansted.

The Roorkee Treatise seems to call it calcareous tufa when it is found in solid layers, and in the undulated districts ; and kunkur when the well known vesicular nodule of the plains is meant. It appears to be, the Treatise says, a species of subsoil tufa formed by the deposition of calcareous matter extracted by the surface waters in minute portions from the beds of sand and clay, and re-deposited in a concentrated and irregular form.

I cannot help remarking that after reading this definition, the mind does not feel satisfied that a geological problem has been satisfactorily solved, and must inquire if the causes of origin attributed to this calcareous tufa, correspond with those generally acknowledged by geologists. If therefore I return to David Page, I find that calcareous tufa is a porous or vesicular carbonate of lime, generally deposited near the sources, and along the courses of calcareous springs, incrusting and binding together the objects that lie in the way. Occasionally when such springs discharge themselves into lakes and seas, beds of considerable thickness are formed, producing a light calcareous rock like the Travertine of Italy. When slowly formed in the open air, compact incrustations are the usual result.

The above extracts from David Page, and the study of the admirable descriptions of the glacial period, and of the deposits of calcareous strata to be found in Sir Charles Lyell's elements of Geology, induce me to offer a solution of the problem of the origin of kunkur.

It is, that during the glacial period and after it;

When the boulder drift formation was taking place, and after its termination;

When India was slowly upheaved by volcanic action out of the deep sea.

Innumerable hot springs, like those of Iceland, covered many points of the Indian soil with calcareous matter, which according to the circumstances in which it found itself when solidifying, took various forms, and petrified various beds of minerals lying in its way.

In support of the above hypothesis, which I humbly submit to the judgment of geologists, I will describe as well as it is in my power, an excellent ground for geological researches situated in the Goordaspore District, between Dinanagar, Madhopore, Pathánkot and the Beas (vide *Plate* LIV). This ground offers a rich field of observation, as it contains large deposits of boulder drift, conglomerate calcareous sandstone, calcareous sand nodules, travertine or kunkur in many varieties of form and of purity as a carbonate of lime, and in some rare elevated spots, calcareous marls, on the surface of which the formation of round and flat nodules, of kunkur is even now proceeding.

I shall avoid in this description classifying any of the formations that I have examined, leaving this classification to men of greater experience. I shall confine myself to stating facts that every body can see and to drawing from them inferences almost self-evident.

If I draw a vertical plan through Madhopore and the Dhangoo cut, I obtain a section of the country which gives me an idea of the formations on which rests the alluvial deposits, and of the way the work of deposition was performed (see *Plate* LV.)

If I start from the Madhopore side, the lowest layer that I can observe is the calcareous conglomerate, the cementing or " the grouting " material of which is visible on many of the pebbles which compose it. Under this lie, I presume, the same strata of shales and clays that are to be found in the Dhangoo cut, and the calcareous sandstone which is found on the other side of the valley of the Ravee. Over the conglomerates appear the boulder drift, cemented with alluvium clay. As the line of the high

shore of Madhopore is continued on the other side of the river, it can be presumed that the deep ravine which leaves perpendicular cliffs of boulder drift, 60 feet high, on the south eastern side was once filled by drift through which the Ravee has cut its present bed.

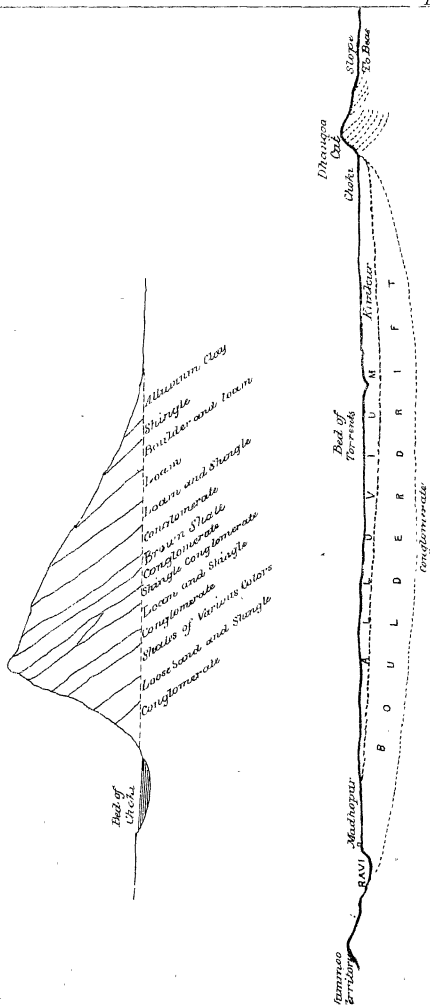
Now if I leave Madhopore to travel in the direction of Pathánkot, I go up for a small distance towards what must have been an ancient shore of the Ravee. After passing it, I go along a ground insensibly sloping downwards, until after passing the torrents, and the town of Pathánkot, I go up by a gentle slope to the Choki torrent, and the Dhangoo hills.

Formerly the Choki running along the summit of the watershed of the country, divided its waters in two principal branches, one of which ran to the valley of the Beas and the other to the valley of the Ravee; but when the Baree Doab canal was made, the Ravee branch of the Choki was found so dangerous, that it was deemed necessary to divert the whole of its water towards the Beas. This was done by making a cut 200 feet deep through the Dhangoo hill. This cut gives to the geologist an insight in the formations which lie under the boulder drift.

As far as I could judge without instruments, the dip of the different layers is about 30°, and directed to the N. E. On the northern side the hill is very steep, and the slope cuts the strata at an angle of about 60°; the slope of the southern side is long and easy. The layers are mostly composed of hard conglomerates alternating with loose sand and shingle, shales of various colors, loam and brown clay, and are covered on the southern side by layers of boulders, loam, shingle, and a last layer of alluvium clay. Now if I ascend to the summit of the hill and look towards the west, I find that the watershed, which somehow has lost its hilly character, turns round towards the S. S. W. until it meets the high grounds or promontory of Bhimpore, and takes the character of a plateau descending rapidly towards the green valley of the Beas, and gently sloping in the direction of the rich plains watered by the canal, and by the Ravee.

Then if I turn towards the N. E., I see on all sides nothing but hills and lofty peaks, and can fancy myself in the middle of a magnificent bay which once contained the estuaries of two great rivers and of numerous torrents.

If after having thus discovered the general features of the surrounding country, I carry my thoughts backwards to the glacial period, I find that

ROUGH SKETCH OF STRATA IN DHANGOO CUT.
(200 feet deep).
Bed of Choki
Alluvium Clay
Shingle
Boulder and loam
Loam
Loam and Shingle
Conglomerate
Brown Shale
Conglomerate
Shingle Conglomerate
Loam and Shingle
Conglomerate
Shales of Various Colors
Loose Sand and Shingle
Conglomerate
Jammoo Territory
RAVI
Madhopur
Bed of Torrents
Choki
Dhangoa Cut
Slope
To Beas
Kunkur
ALLUVIUM
BOULDER DRIFT
conglomerate

volcanic action was upheaving the hill on which I stand, that currents from the west were pushing against the hills, just formed, huge icebergs whose grinding action took away their greater portion, formed the long gap between Dhangoo and Bhimpore, and filled the valleys with their erratics and boulders.

Following now with the rapidity of thought, the slow upward motion which has lifted up the upper surface of the boulder drift nearly 1200 feet above the level of the sea, I see clearly that when the waves were receding, the waters of the Ravee, of the torrents and of the Beas began to cut their present beds through the boulder formation, and their floods were covering with alluvium, not only the boulder drift, but also the beds of calcareous tufa, just issued from the mineral springs. Then the high grounds of Bhimpore acting as a promontory, threw the waters of those floods towards the parent stream. I must now descend from the height overhanging the Dhangoo cut, and visit in detail the grounds that I have just examined from a general point of view. One of the first things that I find is, that Hindoos have collected at the feet of their sacred Peepul trees, all the smaller available stones polished and grooved by the action of the icebergs. Of course I dare not take away these ex-votos of a new kind, afraid to hurt the superstitious feelings of their owners, and I am obliged to leave my collection without specimens of a most curious form.

The object of my next visit is the undulating ground on the N. E. of Pathánkot, from which kunkur has been lately excavated. There I find horizontal strata of vesicular calcareous tufa about one foot in thickness and at depths varying from 6 to 8 feet. The vesicles are well filled with the clay which lies under and over the travertine, and the upper layer of alluvium contains many little bits of the same mineral. Besides this layer of calcareous tufa, I find in many fields a surface kunkur generally cylindrical, and formed evidently round a nucleus. I shall have occasion to, speak again of this surface kunkur.

If I leave the fields on the eastern side of Pathànkot under which lie, I presume, extensive strata of calcareous tufa, and visit both sides of the promontory of Bhimpore and the various cliffs left by the receding waters of the rivers which run now 120 feet below the promontory, and six miles from it, I find on the western side, and in almost every cut formed by the action of rain, water along the slopes, extensive layers of flat kunkur lying horizontally in marl, and the slopes of those cuts covered with little bits

of kunkur, left by the rain water carrying away the alluvium in which they were buried. These beds of flat kunkur are sometimes interrupted by a layer of calcareous sandstone, about 9 inches thick. If I pass to the eastern side of the promontory, and visit also all the natural drainage cuts, I fall on a still greater variety of calcareous deposits.

First of all at Mumeal, over a bed of fine river sand, are layers of calcareous sandstone, of the most contorted and curious shape; over this are beds of loam full of calcareous sand nodules, which look as if they had been formed round nuclei, and some of them assume the shape of sea shells. Whether they are petrified shells or not, I leave to more learned men to settle. These beds are sometimes interrupted by thin bands of calcareous flat nodule.

Further on near Choohan, I met with a small elevated spot, where the ploughs have not yet cut away the ancient marly soil. There I find again the same surface kunkur of Patháukot, but here it is in its original state, rising vertically out of the ground, and surrounding the petrified stems of the jungly plants which grows on those grounds. Here also I find some flat kunkur, whose recent formation somewhat agrees with the description of kunkur found in the Roorkee Treatise, and alluded to before. Here the flat and round kunkur are evidently formed by rain water, laden with calcareous matter, dissolved from the marly soil, which lies in the centre of this kunkur nursery. The way the flat kunkur is formed is most curious; the calcareous matter meets scales made in the ground by the heat of the sun, and slowly converts them in flat nodules. If it is unquestionable, however, that these species of kunkur are formed by the agency of rain water, the first cause of origin is, I think, the mineral springs which originally saturated the marl with carbonate of lime.

Whatever may be the first cause of an excess of lime in the soil, it is certain that running water gave its form to the flat kunkur, as I saw further on, on my way southwards, and half way between Rusoolpore and the canal, the denuded horizontal surface of one of these beds formed many centuries ago, and I could see that the spaces between the nodules were well defined, continuous, threads through which the liquid calcareous matter must have flown.

Going again towards the south as far as Lahri, and on the canal side of the villages called Nya Pind, Kalipore, &c., I find at various depths extensive strata of calcareous tufa in the vesicular form, the upper layer

being the most rich in carbonate of lime, and the lower layer being frequently a gritty nodule, the form of which somewhat resembles a petrified sponge.

I must here bring to its conclusion this small essay, which I am conscious does not do enough to prove that kunkur was formed directly and indirectly by the action of mineral springs, but I shall feel satisfied with the result of my labor, if this little work induces experienced geologists to weigh the value of the hypothesis, and helps them in finding the real cause of origin of kunkur.

Could not also the hypothesis of mineral springs laden at first with carbonate of lime, and at their last stage with sulphate or carbonate of soda, as some of the springs now in activity in the lower range of hills, explain satisfactorily the presence of Reh in some of the soils overlying kunkur.

Whatever may be the worth of the above hypothesis, I hope that this short essay will be found interesting and useful by the Members of the Engineering profession, who have the greatest interest in a thorough knowledge of the kunkurs, our only sources of natural cements.

A. N.

No. LXII.

MANUFACTURE OF CEMENT IN INDIA.

[Vide *Plates* Nos. LVI. and LVII.]

Notes on the Proposed Manufacture of Hydraulic Cements in India.

BY LIEUT.-COL. H. A. BROWNLOW, R.E., *Chief Engineer of Irrigation, N. W. Provinces; and* P. DEJOUX, ESQ., *Executive Engineer of Cement Experiments, Calcutta.*

[NOTE BY EDITOR.—A most interesting report by Lieut.-Col. H. A. Brownlow, R.E., on the means of manufacturing artificial hydraulic cements in the N. W. Provinces of India, was submitted to the Government of India, in August 1870, and was republished as Paper No. CCXCIV., in the First Series of Professional Papers, Vol. VII.

Extracts from that Report have been incorporated in the new Edition of the 1st Volume of the Roorkee Treatise of Civil Engineering, which is now being published at the Thomason College; and in order to render this article complete in itself, and to elucidate the further notes on the subject now published in it, the extracts above alluded to are now reproduced, and will serve as a preface to the new "Notes."]

The following rules for the manufacture of Hydraulic Cements in India are those recommended by Colonel H. A. Brownlow, R.E., Chief Engineer for Irrigation in the N. W. P.

The pure rich lime of the lower Himalayan ranges would be the best substitute for chalk. Practically, it is chalk with the carbonic acid driven off, and by its use we should save much wear and tear in grinding and mixing it with the clay. The hard-

er lime-stones would require stone-crushers and extremely hard mill-stones to pulverise them.

The clay should, if possible, contain oxides of iron, in any proportion up to 15 per cent. ; but it this cannot be secured, any *compact greasy clay free from sand*, will answer our purpose, although, perhaps, not quite so well as the other. The proportion of pure lime added can always be modified according to the chemical composition of the clay used.

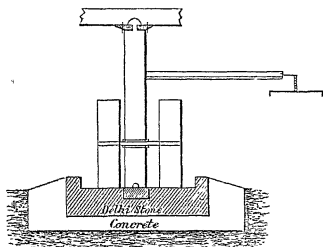
The lime and the clay which it is proposed to mix, must be first *thoroughly dried* in the sun, but the clay should be used as fresh as possible, and any exposure of it to sun and air, further than that absolutely necessary to dry it, should be carefully avoided.

The material must then be separately pounded, either by hand or any simple machine, into pieces not larger than a pea, and the pounded materials should be screened so as to ensure the exclusion of coarse lumps.

The pounded materials should then be passed in certain definite proportions through a hopper between a pair of ordinary flour mill-stones adjusted so as to grind them as fine as flour. It will save much wear and tear, and do the work more thoroughly, if the materials are passed through *two* pair of stones in succession, the first pair adjusted to grind more coarsely than the second.

The exact proportions of lime and clay to be employed will depend upon the chemical constituents of the materials used, and must be fixed on the spot. Generally speaking, there should not be less than 40, or more than 60 per cent. by weight of pure lime, and from 60 to 40 per cent. of clay. Having been fixed, the proportions must be most carefully adhered to, as any carelessnesss in this matter will of course vitiate all future operations.

The pulverised material should then be mixed in a cylindrical vat with a graduated scale on its side, in the proportion of thirty volumes of powder to ten of *boiling* water, in which has been mixed ¼th volume of calcined soda and ½ ℔. of freshly, burned and slaked lime.

From the vat, remove the mixture to a basin in which a couple of mill-stones should be made to revolve on their edges round a vertical shaft, as in the case of a steam mortar mill. The basin should be only just large enough for the stones to revolve in, should be carefully and smoothly paved with hard stone, and should be surrounded by a rim of wood or masonry 8 inches to 12 inches high. The stones should be fixed at slightly unequal distances from the vertical shaft, so as not to run exactly in each other's tracks, and at the outset I should think it would amply suffice to move them by animal power as shown in sketch. They could afterwards be easily connected with the water wheel that drives the mills.

From the edge runners, the mixture should be taken to a pug-mill, and when thoroughly pugged, (being passed through the pug-mill 2 or 3 times if necessary,) should be cut off in small bricks or lumps, not exceeding 2 or $2\frac{1}{2}$ inches in thickness, as it comes out of a shoot fixed at bottom of mill.

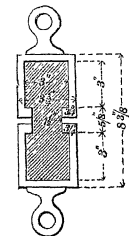
It may not be amiss to remark here that too much pains cannot be bestowed on the thorough incorporation of the raw materials, and in keeping them clean and free from sand and foreign ingredients during the process. As far as any chemical action is concerned, the clay remains almost inert after the mixture has attained a dull red heat, so that it is most important to bring it into the closest contact with the lime, before the burning commences. The presence of sand tends to produce vitrifaction during burning, and is most prejudicial to the cement; clay containing more than $\frac{1}{20}$ of sand should be rejected.

M. Lipowitz objects to drying in the air, and quotes two examples where doing so was found to be most injurious to the cement. But the English manufacturers expose their raw cement freely to the air in the reservoirs, where it sometimes lies for a couple of months before it is burned; and in one factory, I saw it being wheeled direct from the drying reservoirs to the kilns. So that, until experience shows us in India that kiln-dried, is stronger than sun-dried, cement; I should recommend stacking the blocks of raw cement, as removed from the pug-mill, in drying hacks like bricks.

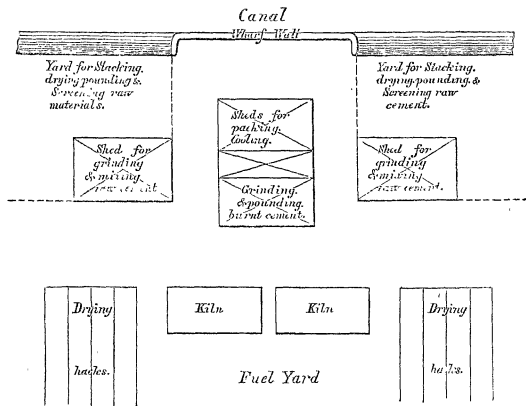
When *thoroughly* dry, the blocks of raw cement should be burned, either in clamps with dried cow-dung, or in a good lime kiln with thoroughly dry wood, or with charcoal, as experience on the spot may show to be most advantageous. The proper degree of exposure to heat should be ascertained and carefully adhered to. The higher the heat to which it is exposed the greater the density of the cement, the greater also its strength and its ultimate degree of induration; while the lighter cements have the property of setting more rapidly.

The burnt cement should then be pounded until it can pass through a screen with meshes the size of a pea, and finally be ground as fine as flour, so that it can pass through a No. 60 gauge sieve (3600 meshes to a square inch). It should then be allowed to cool thoroughly on a dry floor before packing.

Thickess of brick = 1½ inches.

The cheapest packing for India would be in bags or sacks. These would not have any sea voyage to undergo, and the cement would, in all probability, be used tolerably fresh. Where it had to be sent long distances, small barrels could doubtless be purchased at advantageous rates from the nearest commissariat depôt.

A number of samples should be made up of cements formed according to these directions. The samples, when burnt, should be finely pulverised, and, when cool, should be moulded into bricks of the form shown by the shaded portion of marginal diagram. There should be at least a dozen bricks of each sample, and they should be allowed to set under still water for seven days after they have been taken out of the moulds. The lower of the two iron clips shown in the diagram should then be loaded until the bricks are torn in two, and if any of the samples prove themselves capable of supporting an average

weight of 225 to 250 lbs on the area $1\frac{1}{2}$ inch square (or $2\frac{1}{4}$ square inches), I think we may safely adventure upon the manufacture. I have been particular in giving dimensions of the sample brick, as I wish to adhere as exactly as possible to the form of test generally used in England. It would be instructive and interesting to make up and treat in the same way bricks of the best "kunkur" lime.

The samples mentioned above should be carefully made up in the manner laid down, accurately labelled, and tested. The strongest composition having been thus ascertained, steady and persevering efforts at economical production must be made. I am most strongly convinced of the good policy of beginning in the simplest manner, consistent with economy and efficiency. Mistakes can then be easily and inexpensively rectified. The site of the factory should, from the very first be laid out with an eye to expansion of business, and economical working on a large scale. There should be no carrying backwards and forwards, the general arrangement of the works being somewhat as indicated below.

In conclusion, I must add a few words on the manipulation of the manufactured cement, which are, I think, necessary, as it has not been hitherto extensively used in India, and the best cement may be utterly ruined by careless handling on the works. *In the first place, only just so much of it as is required for immediate use should be made up at any one time, as when once it has commenced to harden, it cannot be worked up again* like a mortar containing rich lime. In mixing it with sand or

gravel, *the ingredients should be well mixed together in a dry state*, before any water is added. In adding the water, only pour in enough to make a stiff paste, as flooding the cement is most prejudicial to it. The sand used should be clean and sharp, and when cement is used in brick-work, *the bricks must be thoroughly saturated in water before use*, otherwise they will absorb the moisture necessary for the proper setting of the cement. When used under water, cement must until it has set, be protected from any current.

Portland cement of the very first qualities can be delivered by the manufacturers free on board vessels in the Thames at 10*s.* per cask, containing 400 lbs. nett of cement. The freight to India in vessels sailing round the Cape, and landing charges in India, should not exceed 6*s.* per cask. The Railway charge per cask from Calcutta to Delhi would be Rs. 14·66 at ½ pie per maund per mile. Therefore the cost of 400 lbs. nett of first class English-made cement at Delhi would be Rs. 22·66, say Rs. 23 to cover losses : 400 lbs. weight at 42 lbs. per bushel of 1·28 cubic feet capacity being equal to 4·5 cubic feet. We may take the cost of a cubic foot of English cement at Delhi to be Rs. 5-2-0*

A German analyses gives the following as composition of the Medway clay, which is used in manufacture of most of the London cement :—

Silica, ...	68·45
Alumina, ...	11·64
Oxide of iron, ...	14·80
Soda and potash, ...	4·00
Carb. lime and loss, ...	1·11
	100·00

Dr. Ure says that "all good hydraulic mortars must contain alumina and silica, the oxides of iron and manganese at one time considered essential, are rather prejudicial ingredients." Vicat is of opinion that the peroxide of iron exerts an injurious influence upon hydraulic mortars. M. Lipowitz, a German writer on the subject, whose

* When it may be necessary to import Portland cement into India, the specification for quality should be as follows :—

" The whole to be of the very best quality, ground extremely fine, weighing not less than 112 lbs. to the striked bushel, and capable of maintaining a breaking weight of 750 lbs. on an area of 1½ inches square, or 2¼ square inches, 7 days after having been made in an iron mould, the cement having been immersed in water during the seven days. " It should be packed in fir casks, with staves not less than half an inch thick, each cask having four iron hoops, and being lined with water-proof brown paper. The casks should be of manageable size, and weight, so as to avoid needless knocking about in stowing and transit A larger quantity than 400 lbs. nett. should not be packed in any one cask, and perhaps 300 lbs. would be a better quantity where cement is intended to go far inland. Stow above highest line of bilge water in ships, as damp affects the cement most injuriously. Cement that has become wet through in barrels, and taken a " set," may be broken into lumps, reburnt and pulverised again, a bright red heat of one and a half to two hours duration is quite sufficient to restore the activity of injured cements. I may add that it would be very much better to get it from some of the well-known makers (such as Knight, Bevan and Co., J. B White, and Co., Robins and Co., Hilton Anderson and Co.,) paying a fair price for it, than to go into the market for the cheapest article. Inferior cement of uncertain quality would be worse than the hydraulic mortar we already have in India.

treatise has been translated by Mr. Reid, quotes, with approval, an opinion "that the best clays for cements are those which contain iron up to 10 or 15 per cent. in the form of iron oxydule." General Gillmore says that the clays most suitable for combination with common slaked lime for preparation of artificial cement, contain 30 to 50 per cent. of alumina, and 4 to 5 per cent. of carbonate of lime. He considers that the oxides of iron do not confer hydraulic activity, whatever may be their action at subsequent stages of the induration. If we wish to produce a compound silicate of alumina and lime, which is, according to some, all that is necessary, we must have the following proportions :—

				Per cent.
Lime	2 chemical equivalents = 57 × 2	= 114·0	28·3	
Silica	2 " " = 93 × 2	= 186·0	46·2	64·5
Alumina	1 " "	= 102·8	25·5	35·5
		402·8	100·0	100·0

The best analyses of Portland cement give—

Lime	60	per cent.
Silica	23 to 20	"
Alumina	7 to 10	"
Oxide of iron	5 to 1	"

Alkalies, carb. acid and water. 5 to 9 per cent.

15 per cent of the oxides of iron in the raw clay would give about 4 per cent. in the burnt cement, I think, therefore, that the clay should, if possible, contain oxides of iron in any proportion up to 15 per cent. ; but that if this cannot be secured, any *compact greasy clay free from sand* will answer our purpose, although, perhaps, not quite so well as the other. The proportion of pure lime added, can always be modified according to the chemical composition of the clay used.

Remarks on Lieut.-Col. H. A. Brownlow's Report by P. Dejoux, Esq.

The rates estimated by Lieut.-Col. Brownlow for cement delivered in Delhi are very correct, but it will not do to calculate on more than 4 cubic feet of cement in pretty good order in a cask, as the remainder will be found spoilt during the shipping, or during transit from Calcutta to Delhi.

I have myself received in Calcutta nearly 10,000 casks of cement, and from experience I always found an average of 4 cubic feet of cement in good order per cask.

Accordingly the rate of Portland cement at Delhi should be 5·66, instead of 5·2.

I do not quite agree with Lieut.-Col. Brownlow as regards the advantage in India of using clay and pure slaked lime instead of clay and *chalk*. Without considering the increase in the cost on account of the double burn-

ing, I think the burning is always more difficult in one case than in the other, and the tenacity of the cement is never so good.

If a prejudicial action takes place on account of the Oxyde of Iron, I would advise the use of clay either entirely free from, or containing a small portion of it.

Many cement stones in France yielding cements nearly as good as Porttand cement contain little or no Oxyde of Iron.

In the case of Portland cement sent from such a distance as England to Delhi, the cement will always lose a certain amount of its strength.

My experience authorizes me to say that it loses in ordinary circumstances ¼th of its strength, and if left in godowns for six months, it will loose at least ⅓rd of its original strength.

It should be borne in mind that the cement casks are always placed at the bottom of the ships, and exposed to the moisture and dampness therein, that the unloading in Calcutta is, and will always be done in a more or less careless manner, and that the great heat of this country affects the quality of the cement to a certain extent.

Considering the question of the loss of strength in the cement imported from England, my opinion is that it is possible, if great care is taken in the manufacture, to make in India cements, artificial or natural, which will be about the same kind, and the same quality as some of the French cements, which, excepting the Boulogne cement, possess from ¼th to ⅓th of less tenacity than the English Portland cement of good quality. Such being the case, the cement which will be manufactured in India may be as good as that received from England; but of course at the same time ¼th inferior (for the reason above adduced) to the cement of fresh quality used at home.

The rough calculations I have made about the probable cost of cement manufactured in India show that it will vary from Re. 1 to Rs. 1-4 per cubic foot in the case of artificial cement, and from 9 to 14 annas in that of natural cement.

In the Bengal ghooting or kunkur stones, I have analyzed, I found a proportion of clay varying from 26 to 34 per 100.

This result impressed me with the idea of trying the possibility of manufacturing either Roman or Portland cement with such stones, in pulverizing those which were not too hard and making bricks, &c., or in extra burning, in their natural state, those which are homogeneous.

I may now safely say that as regards preliminary experiments, I have already succeeded in obtaining slow and quick setting cements, although I am proceeding with further experiments on that score.

I quite agree with Lieut.-Col. Brownlow as regards his proposal to aim first at the utmost simplicity of machinery and plant necessary for the manufacture.

I am of opinion that the best kind of fuel for burning Portland cement is coke, and will place charcoal in second order.

But coal also may answer, as I have seen it used in France.

As I am, however, about to try to burn cement with coal, I will be able in a short time to afford a more decided opinion on the subject.

I do not quite agree with Lieut.-Col. Brownlow as regards his opinion of using for the mixture of materials the dry and German system, instead of the wet English.

It may be said that principally when using pure slaked lime and clay, the German system is superior to a certain extent, but it is also more expensive.

Mr. Reid in his treatise about cement says, that the two principal inconveniences arising from the English system are :—

1st.—That a much larger area is necessary in the English system than in the German one, and consequently in a country where the value of the land is always high, it increases to a great extent the amount of the capital invested in the manufacture of cement.

2nd.—That it requires about two months for the materials in the vats to dry, before being moulded into bricks.

As regards the 1st point, there is at present in India hardly any difficulty in the acquisition of land under the provisions of Act X. of 1870.

Referring to the 2nd point, I should say that in a country so hot as India, the evaporation being much more rapid, it is to be expected that the time necessary for drying will be comparatively *much* less.

I think the proportion of materials used in the manufacture of artificial Portland Cement will vary as follows :—

1st.—For artificial cement made of a mixture of chalk and clay.

From 3 chalk and 1 of clay (in measure).
To 4 ,, 1 ,,

2nd.—In the case of artificial cement, made of pure slaked lime and clay.

From 5 lime and 2 of clay (in measure).
To 5 lime and 3 of clay.

Suggestions about manufacture of Portland Cement.

(1). Except the remarks I have already made, I quite agree with Lieut-Col. Brownlow an all other points. I would however advise, as regards the details of manufacture, to follow the treatise of Mr. Reid on cements.

(2). *Kilns.*—As regards kilns for a small factory, I would advise their construction according to the sketch of Mr. Reid's book, but making them ⅓rd smaller, and increasing the height of the tapering dome by three feet.

(3). *Experiments.*—I would advise the construction at once of a small kiln, for the trial of samples of different kinds of lime and clay in various proportions; the balls for samples may be made of clay and chalk, or lime reduced in impalpable powder, and mixed in water in a tub: the water is on the following day to be removed by decantation, and the substance is then to be exposed to the sun until the evaporation reduces it into a plastic paste, with this balls may be made about two inches in diameter, and dried well; these balls may then be burnt, and when reduced to powder, a stiff mortar made with the cement thus obtained, which can be tested under water by means of the Aiguille of Vicat. Some cakes or balls made with this mortar may be left exposed to the air.

(4). *Natural cement.*—In France the Engineers have been using for several years cement proceeding from the burning, in the same way as for Portland cement, of marly clays of different kinds.

I have already found from the hills of Margohi and Rohtas, near Dehree in the Soane circle, two kinds of clay, which (mixed together in certain proportions and at times with a feeble addition of pure clay) will yield Portland and Roman Cement.

Every sort of clay giving a strong effervescence with hydrochloric acid, may be considered as marly clay, and may be found useful in the manufacture of cements.

The analysis of different sorts of clay, give the following results:—

Yellow marly clay.	Per cent.	White marly clay.	Per cent.
Carbonate of Lime, ...	60·65	Carbonate of Lime, ...	80·00
„ Magnesia, ..	14·35	„ Magnesia traces, but not appreciable,	
Oxide of Iron, ...	0·67	Oxide of Iron, ditto ditto., ..	
Clay { Silica, Alumina, }	23·33	Clay { Silica, Alumina, }	20 00
Sand, ...	1·00	Sand, ...	0·00
Total, ...	100·00	Total, ..	10·00

(5). *Cement of Boulogne.*—The best marly clay used in France is that found in Boulogne, with which Messrs. Demarle and Co., manufacture a cement in high demand in France.

I have been using it in large quantities for three years in the maunfacture of artificial stone (Coignet's system), and found it even sensibly better than the Portland cement of Messrs. White Brothers, which is considered as one of the best sort in England.

The Boulogne marly clay contains from 19 to 25 per 100 of clay.

Every sort of clay containing more than $\frac{1}{5}$th per 100 of sand is to be rejected.

To be certain of a good homogeneity the clay is pulverized and mixed with water in vats, the water is then removed by decantation, and the clay being thus by evaporation in a sufficiently stiff state to be moulded, balls are made of it and burnt in a kiln up to a white heat.

The white heat is necessary for the spreading of the bad parts, which are picked, and rejected carefully after the burning.

The cement is afterwards ground in fine powder, and sifted through a sieve of 60 meshes to 1 inch.

(6). *Cement in the neighbourhood of Paris.*—Sometimes clays may be found homogeneous enough to enable their being burnt without the process of either pulverization or washing. The clay found near Paris contains about the same proportion of Silica and Alumina as that of Boulogne. Such descriptions of marly clay are found (in beds) close to the beds of Gypsum (or Sulphate of Lime); great care must however be observed in selecting them to avoid the mixture of Gypsum with them. These may be burnt in their natural state, and treated after the same manner as the cement of Boulogne.

The best factories are those of Messrs. Barbier and Co. at Paris, Chronne, and Argenteuil, Massrs. Slacker and Letellier at the Butts Chanmont, the Moulineaux and the Rainey.

I used these cements, particularly the first sort, for the building of several miles of sewer in Paris, and found it not much inferior to the English Portland.

(7). *Marly clays.*—I feel almost sure that marly clays of about the same composition as those of Boulogne or Paris may be found in the proximity of many lime quarries now existing in India, and I opine therefore that a careful search will enable the discovery of materials well adapt-